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TERRAIN INVENTORY OF THE KANANASKIS LAKES MAP AREA, ALBERTA

L.E. Jackson, Jr.

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Cover

The Okotoks Erratic or Big Rock. If reassembled into a single block, it would measure 41x18x9 m. The mass of this pebbly quartzite erratic is estimated at 16 400 tonnes. GSC 204343-B

Critical reader

D.A. St-Onge

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CONTENTS

1 Abstract/Résumé
1 Introduction
1 Acknowledgements
2 Previous Work
2 Quaternary geology
2 Soil mapping
3 Geotechnical investigations and investigations of surficial processes
3 Hydrological investigations
3 Methodology
4 Bedrock geology
5 Quaternary stratigraphy
6 Terrain inventory
7 Morainal deposits
7 Texture of surface tills
8 Colour
8 Atterberg limits
10 Unified Soil Classification
10 Clay mineralogy
13 Expansiveness
14 Moisture content
14 Compressive strength and penetration resistance
15 Standard Proctor and in situ densities
16 Topographic form and mapped terrain units
20 Glaciolacustrine and lacustrine deposits
21 Texture
21 Stratification and colour
23 Atterberg limits
24 Expansiveness
24 Moisture content
24 Unconfined compressive strength and penetration resistance
24 Standard Proctor and in situ densities
25 Topographic form and mapped terrain units
26 Glaciofluvial deposits
27 Modifying surficial processes
27 Vegetation and land use
27 Colluvial deposits
28 Colluvial blankets and veneers on s_2 slopes or on slopes of less than 5°
31 Colluvial blankets and veneers on s_1 slopes
31 Coarse bouldery colluvial fan and apron deposits
32 Rock glacier
33 Colluvium resulting from periglacial processes
33 Landslide deposits
33 Eolian deposits
33 Texture and modifying processes
34 Vegetation and land use
34 Alluvial deposits
34 Alluvial plains
34 Alluvial terrace deposits
35 Alluvial fan deposits
35 Organic deposits
35 Conclusions
36 References
40 Appendix 1: Clay mineral preparation methods

Tables

4 1. Rates of erosion and frequencies of significant suspended sediment transport for monitored basins in the study area for available periods of record
5 2. Generalized stratigraphy of the study area
8 3. Summary of geotechnical properties, land use and potential hazards of terrain units shown in Map 2-1984
9 4. Mean weight per cent and related statistics of the coarse fraction of surface tills of the study area
11 5. Atterberg limits of sampled tills of the study area
12 6. Survey of engineering properties of surface tills from pre-existing exploratory foundation borings, Foothills and Prairies

13 | 7. Estimates of abundances of clay minerals and clay-size minerals in tills of the study area
22 | 8. Survey of engineering properties of glaciolacustrine and lacustrine deposits from pre-existing foundation borings
25 | 9. Survey of engineering properties of lacustrine deposits from the north dam site, Chain Lakes Reservoir

Illustrations

in pocket | Map 2-1984 Terrain inventory, Kananaskis Lakes, Alberta

Figures

2 | 1. Location of study area and major drainage features
6 | 2. Structure provinces
10 | 3. Cumulative weight per cent plots of textures of surface tills
10 | 4. Mean cumulative weight per cent textural curves for surface tills
11 | 5. Textural classification of surface tills
13 | 6. Plasticity index vs. liquid limit for surface tills
14 | 7. X-ray diffractograms for clay fractions of surface tills
15 | 8. Clay activities of till and glaciolacustrine sediments
16 | 9. Proctor maximum dry density vs. plasticity index for highway boring samples
17 | 10. Rolling moraine and kame features adjacent to Highwood River
19 | 11. Hummocky moraine along the north end of the Porcupine Hills
19 | 12. Coarse bouldery glacial rubble south of Lawson Lake
20 | 13. Textural classification of glaciolacustrine sediments
21 | 14. Finely laminated glaciolacustrine sediments
23 | 15. Plasticity index vs. liquid limit for glaciolacustrine sediment samples
24 | 16. Tilted barbed wire fence on roadcut through glaciolacustrine sediments
25 | 17. Standard Proctor maximum dry density and optimum moisture content vs. plasticity index for samples obtained from highway borings in easternmost Foothills and Prairies
27 | 18. Pitted planar glaciofluvial deposits along Pekisko Creek
28 | 19. Cumulative weight percentages vs. grain size fractions less than 2000 μm for colluvial material
29 | 20. Plasticity index vs. liquid limit for colluvial samples
30 | 21. Clay activities of colluvial deposits
30 | 22. Active rock glaciers on the southwest flank of Mount Bogart
33 | 23. Patterned ground on top of Plateau Mountain

TERRAIN INVENTORY OF THE KANANASKIS LAKES MAP AREA, ALBERTA

Abstract

The physical properties of the surficial deposits of that part of the Kananaskis Lakes map area within Alberta, and physical processes that shape these deposits vary with the geological and geomorphologic setting in which they are found. Till and glaciolacustrine sediments in the Front Ranges have low plasticity indices due to their stony texture and large content of nonclay minerals in their clay size fractions. Many of the deposits in the Front Ranges are subject to rapid geomorphic processes of erosion and sedimentation, such as snow and rock avalanches, landslides, and debris flows. Tills of the Prairies and easternmost Foothills are less stony, are richer in clay, and have higher plasticity indices than those in the Front Ranges. Clay minerals in deposits of the Front Ranges are primarily illite, chlorite, and kaolinite; those in the easternmost Foothills and Prairies are interstratified montmorillonite and illite, chlorite, and kaolinite. Geomorphic processes acting upon deposits within this area are slow and noncatastrophic, except for flooding along streams. The Foothills belt proper is characterized by deposits and geomorphic processes intermediate and transitional between the Front Ranges and easternmost Foothills-Prairies. Surveys of existing foundation engineering data on surficial deposits are presented.

Résumé

Les propriétés physiques des formations en surface dans la région levée des lacs Kannaskis en Alberta et les processus d'érosion qui les modèlent varient suivant le milieu géologique et géomorphologique où elles se trouvent. Le till et les sédiments glacio-lacustres des chaînes Frontales ont une faible plasticité à cause de leur texture pierreuse et d'une argile qui contient une forte proportion de minéraux non-argileux. Un grand nombre de ces formations est sujet à de rapides processus morphologiques d'érosion et de sédimentation; on peut citer, par exemple, les avalanches nivales et rocheuses, les glissements de terrain et les coulées boueuses. Les tills des Plaines et ceux de l'extrême est des Foothills sont moins pierreux, de ce fait, leur teneur en argile et leur indice de plasticité sont plus élevés que ceux des chaînes Frontales. Les minéraux argileux des formations supercielles des chaînes Frontales sont, en premier lieu, l'illite, la chlorite et la kaolinite; ceux de l'extrême est des Foothills et des Plaines sont interstratifiés comme suit: montmorillonite et illite, chlorite et kaolinite. Les processus morphologiques agissant sur les formations de la région étudiée sont lents et non-catastrophiques, à l'exception, toutefois, de débordements de cours d'eau. La région des Foothills est caractérisée par des formations et des processus morphologiques intermédiaires et transitoires entre les chaînes Frontales et l'extrême est des Foothills et des Plaines. On trouvera dans cet ouvrage des données géotechniques sur des fondations construites sur des formations en surface.

INTRODUCTION

The geographical area under study comprises the Alberta part of the Kananaskis Lakes map area (82 J) and is bounded by 114°W on the east, the Continental Divide along the west and 50°N and 51°N, respectively, to the south and north (Fig. 1). The study area covers approximately 8200 km^2 and includes a great diversity and variety of topography, bedrock and surficial geology, vegetation, climate, and human land use. The population of the area is primarily concentrated in the rapidly growing urban centre of Calgary with a present population (1981) of 592 743. Smaller towns and villages are scattered in the northeastern quadrant of the study area. These smaller urban centres have historically been service centres for agriculture and the oil and gas industry but are increasingly becoming bedroom communities of Calgary. The rapid influx of population into Calgary and adjacent areas, declining provincial, national and world energy resources, increasing demand for food and wood products, increasing pressure on land for recreational lands, and increasing demands for water have set the scene for current and potential land use conflicts within the study area. For example, open pit coal exploration is highly probable for several locations within the Foothills and mountains of the study area. Such projects may present serious conflict with other resources such as wildlife, recreational lands, and clean water. Small country estates are proliferating in the northeast part of the study area and are, in some cases, removing valuable farmland from production. Increasing human activities in the mountainous parts of the study area will more and more place people in close proximity to potentially hazardous periodic and rapidly occurring geological processes such as snow and rock avalanches, debris flows, floods, and landslides.

Successful resolution of land use conflicts such as the above examples will only be accomplished through careful planning. A prime ingredient in such planning must be a consideration of the physical properties of surficial deposits, and the processes that act on them. Insight into these properties and processes in turn, cannot be gained without a knowledge of the stratigraphy and geological history of the deposits themselves. To these ends, this report presents the results of a terrain inventory of the Alberta part of the Kananaskis Lakes map area (82 J) carried out during the years 1974-1976.

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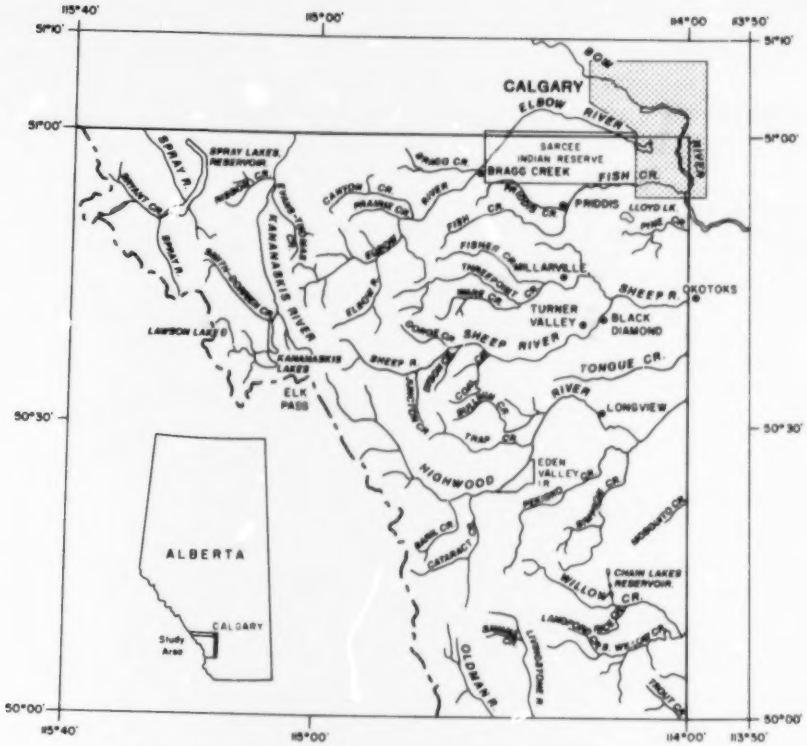

Figure 1. Location of study area and major drainage features.

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D.A. St-Onge critically read this manuscript and provided many valuable suggestions for improvement. All errors of fact or conclusion, however, are entirely the responsibility of the author.

PREVIOUS WORK

Terrain inventory, as used in this report, includes the description of the morphology of the land surface and a qualitative and quantitative characterization of both the unconsolidated deposits immediately underlying the surface and physical processes which erode, deposit, or modify these deposits. Terrain inventory draws upon elements of several disciplines in the earth sciences including surficial geology, soil science, engineering geology, and hydrology. Previous terrain analysis oriented work in the study area will be reviewed by field of enquiry.

Quaternary geology

Previous investigations of the Quaternary geology in and around the study area have been reviewed in detail by Jackson (1977, 1980, 1981), Jackson et al. (1982), and Mott and Jackson (1982) and will not be repeated here for the sake of brevity. The eastern third of the study area has long been recognized as a zone of interaction between ice sheets originating in the Rocky Mountains and the Canadian Shield. Major investigations began with Dawson and McConnell (1885, 1895) and Dawson (1886). Little work was done in and around the map area between the turn of the century and the early 1950s. From this period onward, a number of comprehensive studies were carried out near the Kananaskis Lakes map area. These studies include Stalker's work in the High River, Fort MacLeod, Red Deer, Fernie and Drumheller map areas (1957, 1958, 1960a, 1961, 1963, 1973); Rutter (1972a, b) in Bow Valley; and Tharin (1960) in the Calgary area. More recently, other studies of parts or all of the present map area have been carried out including work by Alley (1973), Alley and Harris (1974), and Jackson (1977, 1978, 1980). Detailed mapping and stratigraphic investigations have been carried by the Alberta Geological Survey.

Soils mapping

The earliest soil mapping of the study area was carried out by Wyatt and Newton (1925, 1942) in the MacLeod and the Calgary-Blackfoot map areas, respectively. These projects covered the study area only from the eastern margin to approximately the first range of Foothills, which includes all of the (commercially) arable land. These studies classified soils into pedologic zones with further subdivision by soil texture and parent material in the Blackfoot-Calgary soil survey. The Blackfoot-Calgary soil survey has been updated (Waytt et al., 1960). Terminology in these surveys has since been supplanted by "System of Soil Classification for Canada" (Canada Department of Agriculture, 1974). In current terminology, the soils of the Prairies of the eastern one third of the study area are primarily black chernozems,

with texture varying with parent material. Increasing precipitation westward and increasing forest cover cause the black chernozems to give way to luvisols in the Foothills. The first mapping of mountain soils was carried out by Crossely (1951) in lower Kananaskis Valley, using the now superseded genetic categories of alluvium, chernozem, rendzina, brown forest, and podzol. A detailed textural study of soils in lower Kananaskis Valley was carried out by Duffy and England (1967). Jeffrey et al. (1968) investigated surficial deposits, soils, and vegetation in upper Oldman River Basin in an attempt at unified landscape classification. Rutter (1968) suggested a method for qualitatively predicting soil erosion potential of forest soils based on such factors as slope steepeness, texture, and content of cementing carbonate fines. Pawluk et al. (1968) classified soils of the Porcupine Hills as predominantly brunisols, luvisols, and regosols developed upon sandstone and shale bedrock of Tertiary age. Mee (1971) mapped the soils of the Porcupine Hills. Karkanis (1972) mapped the soils of Kananaskis Valley using the terminology of the 1974 System of Soil Classification for Canada. Osborn and Jackson (1975) reviewed soil mapping in Kananaskis Valley.

Geotechnical investigations and investigations of surficial processes

The majority of engineering geology studies within the study area are unpublished highway and site investigations. A compilation of exploratory engineering borings with the city of Calgary up to 1972 was assembled through a project funded by the Geological Survey of Canada. Meyboom (1961) investigated the groundwater geology of the city of Calgary: a map rated the permeability of various surficial units within the city of Calgary and surrounding area. A study of the Quaternary geology of the Calgary urban area carried out by the Alberta Geological Survey partly overlaps with the present study area (Fenton et al., 1981; Proundfoot et al., 1981; Nowak, 1981; Shetsen, 1981; Moran, 1986). The geotechnical properties of the Quaternary deposits were determined as a part of this study.

Few studies of surficial processes exclusive of hydrological studies have been previously carried out within the study area or adjacent areas. Gardner (1967, 1968, 1969, 1970a, b, 1971a, b, 1973) described geomorphic processes and their rates on high mountain slopes in the Lake Louise area along the continental divide to the northwest of the study area. Harris (1971, 1973) examined rates and processes of soil creep in Bow Valley between the continental divide and Calgary immediately north of the study area. Harris found soil creep to be most active in the late summer and fall when soil moisture contents were the lowest. Harris (1979) and Harris and Brown (1982) investigated the patterned ground on the top of Plateau Mountain and found these features to be underlain by active permafrost.

Hydrological investigations

The Water Survey of Canada has collected water discharge data for some streams in the study area. Of this network, only three stations, Willow Creek above Chain Lakes, Highwood River at mouth, and Elbow River at Bragg Creek, have been monitored for suspended sediment discharge and are large enough to give some indication of regional rates of erosion. Table 1 lists values for total transported suspended sediment in tonnes per square kilometre and statistics indicating when the sediment is transported. These data indicate that between 50 and almost 100% of the suspended sediment eroded and transported in these three basins is moved out of the basins in the months of May and June. Climatic records (Environment Canada, 1971) for the period 1941 to 1970 show these months to be the wettest of the year; consequently this is when the highest stream flows and sediment discharges occur. Storms occurring during May and June are usually regional in extent, but may vary from one basin to another in their intensity of rainfall (Alberta Department of the Environment, 1973). Furthermore, while high flows and sediment discharges occur in adjacent basins, water and sediment discharge per unit area may be much greater in one basin than another due to variations in rainfall intensities within the same storm. Runoff from these storms (two or three days in length) usually transports much of the sediment eroded in a given year as evidenced by per cent total sediment discharge figures for the five largest sediment discharge days per year (Table 1).

In addition to basic data collection, some interpretative hydrological studies have been carried out in the study area. Hollingshead et al., (1973) investigated rates of sedimentation in Glenmore Reservoir in Calgary and found an average annual erosion rate for the 1217 km^2 of the Elbow watershed upstream of the reservoir to be 84 tonnes/km^2 for the period 1932 to 1968. They cautioned that these rates of sedimentation may be anomalously low due to the absence of large floods during the period of record (1932-1968) similar in magnitude to those occurring earlier in the century. Hollingshead (1971) investigated the mechanics of bedload movement on Elbow River near Bragg Creek using a specially designed gauging station.

The Alberta Department of the Environment (1973) examined flood frequencies on Bow River and mapped out flood hazard areas based on past stream discharge records and historical information and investigated the hydrometeorological origin of flooding within the Calgary area.

A currently active study of the hydrological effects of logging has been operated since 1962 in Marmot Creek Basin, a tributary to Kananaskis River, by Environment Canada and other federal and provincial agencies.

METHODOLOGY

Terrain analysis of the Kananaskis Lakes map area was initiated through preliminary airphoto interpretation of 1:62 500 to 1:30 000 scale airphotos. Terrain units were mapped on the airphotos using a legend scheme modified from Fulton et al. (1975) on the basis of surface morphology and inferred physical processes. These units were substantiated where possible by data from previous geological studies and geotechnical investigations. At this point field investigations were initiated.

Terrain units were investigated in the field along with their stratigraphic relationships. Where surficial deposits were found to have wide enough distribution and sufficient homogeneity so that their physical and engineering properties would be of importance relative to the scale of the map (1:125 000), they were sampled. In the mountains and Foothills of the area, surficial deposits fitting the above criteria occur predominantly within the valley bottoms. Upland and slope deposits exhibit such variability in texture that sampling of these deposits was not practical. In the more accessible and less hilly eastern third of the area, sampling distance within individual terrain units was 6.6 km (four miles) between samples. Exceptions were made where more detailed sampling was required to delineate variations in provenance of surficial units, abrupt changes in physical or engineering properties occurred over small distances, and where several units in a stratigraphic sequence required sampling.

Table 1. Rates of erosion and frequencies of significant suspended sediment transport for monitored basins in the study area for available periods of records

Year	Qs total (tonnes)[1]	Qs/km² (tonnes/km²)[2]	% Total Qs			Dates of occurrence
			May	June	5 days of largest Qs	
Willow Creek above chain lakes (Station No. 5AB28)[3] (Area upstream 165.3 km²)						
1965	5 402	32.6	-	96.9	82.6	June 17-21
1966	2 327	14.1	8.6	83.3	73.0	June 4-8
1967	30 938	187.2	69.8	29.8	66.4	May 30-June 3
1968	587	3.6	15.5	41.2	27.0	June 7-11
1967	18 759	113.5	1.3	70.4	75.1	June 25-26, 29-30, July 6
1970	3 302	20.0	45.8	52.4	70.0	May 5-6, June 13-15
1971	658	4.0	12.3	75.8	66.4	June 5-9
1972	1 132	6.8	58.0	7.6	24.9	June 14-17, August 23
1973	1 247	7.5	83.4	6.1	60.7	May 17, May 25-28
		$\bar{X}$ = 43.3				
Highwood River at mouth (Station 05BL024)[4] (Area upstream 4052 km²)						
1970	380 579	93.9	2.8	97.0	90.7	June 14-18
1971	-	-	-	-	-	-
1972	240 424	59.3	43.7	44.1	38.1	May 29-June 2
1973	79 306	51.5	72.5	22.4	45.0	May 26-28, May 31
		$\bar{X}$ = 68.2				
Elbow River at Bragg Creek (Station 05BJ004)[5] (Area upstream 805 km²)						
1969	60 833	75.6	3.2	76.1	66.0	June 25-26, 29-30
1970	-	-	-	-	-	-
1971	18 655	23.2	6.5	91.4	84.3	June 5-9
1972	14 296	17.8	29.2	67.5	53.2	May 30-June 2, June 10-11

Qs - Suspended sediment discharge
$\bar{X}$ - Arithmetic mean

[1] 1 tonne = 1.102 short tons
[2] 1 tonne/km² = 2.855 short tons/mi²
[3] Data for 1965 for June-September only
[4] Data for 1970 May-August only
[5] Data for 1969 May-October only

Airphoto mapping supplemented by field data was transferred to the base maps at a scale of 1:50 000. These maps were then reduced to the publication scale of 1:125 000 (Map 2-1984).

Samples taken with shovel or hand auger for characterization of the physical and engineering properties of terrain units were analyzed by the Engineering and Sedimentology Laboratory of the Geological Survey of Canada in Ottawa. Test and analyses included textural analyses, Atterberg limits, and X-ray diffraction analysis of clay fractions.

Map 2-1984 and the results of field investigations and sample analyses, plus a compilation of previous geological and geotechnical investigation, were combined into this final report.

BEDROCK GEOLOGY

The study area was a region of subsidence and deposition throughout most of Paleozoic and Mesozoic time. The Paleozoic Era, especially the Devonian and Mississippian periods, was characterized by carbonate sedimentation. Mesozoic sedimentation during the Triassic and Jurassic was dominated by clastics with their source to the east of the study area (Douglas et al., 1970). By Lower Cretaceous time, the first pulses of the Laramide Orogeny caused uplift to the west and a major influx of clastic sediment from western sources were contributed to the epeirogenic sea which covered the study area. Bally et al. (1966) postulated a foredeep migrating across the study area during the Cretaceous and early Tertiary ahead of the west to east progression of mountain building in the Cordillera during this time period. This migrating foredeep served as a focus for

depocentres As a consequence, Cretaceous and Paleocene shallow marine and continental clastics progressively reach their greatest thickness from west to east with decreasing age.

No Tertiary deposits younger than Paleocene are found within the study area. Gravels capping some of the hills in and near the eastern margin of the area have not been dated. They are coarse and contain a significant percentage of carbonate clasts in contrast to older gravels which cap uplands farther east. Consequently, I regard them as early Pleistocene outwash, although this interpretation is certainly a speculative one. Table 2 lists bedrock formations found in the study area.

The study area includes five major physiographic regions (Bostock, 1948; Bally et al., 1966). From east to west they are the Interior Plains (referred to henceforth as the Prairies), the Porcupine Hills, the Foothills, the Front Ranges, and the Eastern Main Ranges (Fig. 2). The Prairies region within the study area is underlain by broadly and gently folded nonmarine sandstones and shales of the Paleocene Porcupine Hills and Paskapoo formations and underlying Paleocene to Upper Cretaceous bentonitic shales and sandstones of the Willow Creek Formation and clastics of the St. Mary's River Formation (Douglas, 1950). These units outcrop at progressively higher elevations to the south and form the Porcupine Hills – essentially an uptilted continuation of Prairie structure. The surficial expression of the Prairies structure within the map area is that of rolling hills with broad valleys cutting across strike at several points. The elevation of uplands increases from about 1200 m in the Calgary area to the northeast to in excess of 1500 m in the Porcupine Hills in the southeast corner of the study area. Relief ranges from 100 m in the Calgary area up to 300 m in the Porcupine Hills.

The Foothills are underlain by extensive northwest-striking, west dipping thrust sheets composed of Mesozoic clastics. Secondary folded structures are also common. Topography consists of rounded, northwest trending ridges and valleys. Elevation of ridge tops increases from 1220 to 1370 m along the eastern margin of the Foothills to 1800 m or more near the Front Ranges. Relief between valley bottoms and ridge tops ranges from less than 100 m along the eastern Foothills to 300 to 500 m near the Front Ranges.

The Front Ranges consist of imbricated northwest-striking, west dipping thrust sheets of Paleozoic carbonates and shales and Mesozoic clastics. Topography consists of craggy northwest trending asymmetric ridges and valleys. Both have been extensively sculptured by glacial processes. Elevations of ridges range up to and locally exceed 2600 m with peaks at 3000 m; relief ranges up to 1600 m or more.

Only a small area of the Eastern Main Ranges is included in the study area. This area is underlain by nearly flat-lying thrust sheets of Paleozoic carbonates and clastics. Relief, elevations, and freshness of glacial landforms are comparable to those of the Front Ranges.

QUATERNARY STRATIGRAPHY

The Quaternary stratigraphy and history of the study area are discussed in Jackson (1980, 1981) and are summarized here:

Glacial deposits representing four glaciations are found in the study area. The oldest glacial episode – Glacial Episode One – is considered Illinoian in age on the basis of land mammal chronology. Scattered deposits of this episode are found in the Porcupine Hills and uplands to the west above 1400 m. The evidence suggests single, presumably nonsynchronous, glacial advances from both the Canadian Shield and Rocky Mountains.

Table 2. Generalized stratigraphy of the study area (modified from Gordy et al., 1975, and Bally et al., 1966)

Age	Unit	Thickness (m)
Tertiary	Porcupine Hills Formation: nonmarine sandstone, mudstone, siltstone, conglomerate	>1210
Tertiary	Willow Creek Formation: nonmarine shales and sandstones	160 - 80
Tertiary	Brazeau Formation: nonmarine sandstone, mudstone, siltstone, conglomerate	
Cretaceous	Belly River Formation: nonmarine sandstone, mudstone, and shale	360 -1210
Cretaceous	Wapiabi Formation: marine shales, siltstone, and minor sandstone	330 -550
Cretaceous	Cardium Formation: marine sandstone, siltstone, and shale	9 -130
Cretaceous	Blackstone Formation: marine shale and minor sandstone	120 -300
Cretaceous	Blairmore Group: nonmarine sandstone, shale, and conglomerate	300 -1940
Cretaceous	Kootenay Group: nonmarine sandstone, shale, siltstone, and coal	0 -1210
Jurassic	Fernie Formation: marine shale and sandstone	30 -300
Jurassic	Spray River Group: marine siltstone, sandstone, mudstone, shale, and dolomite	0 ->600
Triassic		
Mississippian	Rundle Group: marine limestone and dolomite; grades laterally into the Rocky Mountain Group: dolomite and quartzite	240 -950
Mississippian	Exshaw and Banff formations: marine limestone, shale, and dolomite	150 -330
Devonian	Alexo and Palliser Formations: marine limestone and dolomite	300 -630
Devonian	Fairholme Group: marine dolomite	290 -450
Cambrian	Eldon, Pika, and Acrtomys Formations: marine limestone, dolomite, and shale	210 -460
Cambrian	Mount Whyte, Cathedral, and Stephen formations: marine limestone, dolomite, and shale	240 -880
Cambrian	Gog Formation: quartzite, conglomerate, shale	300 -670

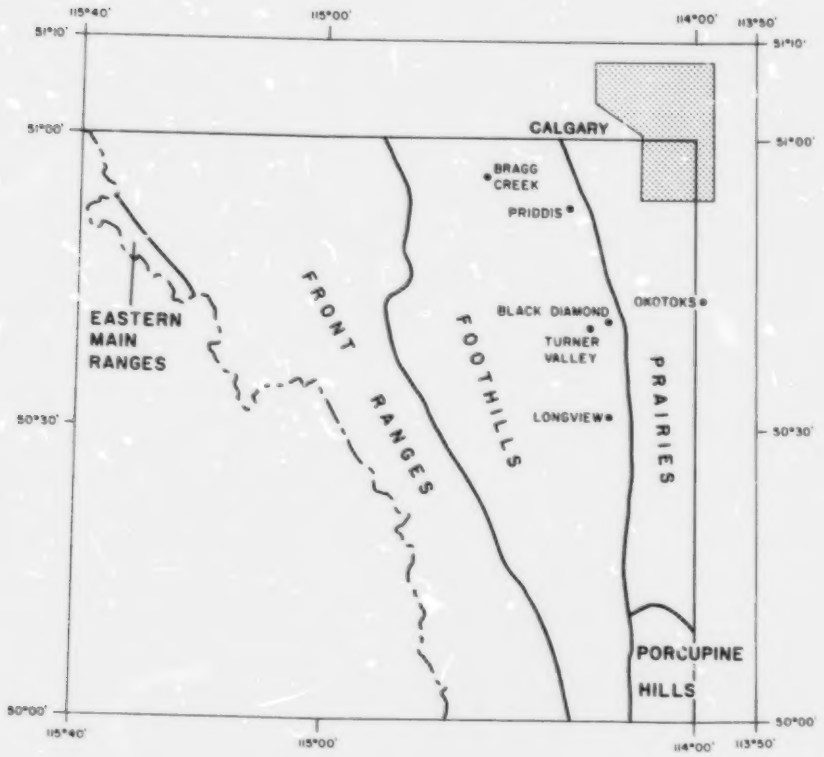

Figure 2. Major structural provinces of the study area.

The next oldest glacial episode – Glacial Episode Two – is also presumably Illinoian in age also on the basis of land mammal chronology. During this glaciation, ice from the Rocky Mountains was diverted southward across the Foothills by the Keewatin ice mass in the area of 114°W. Ice margins reached 1400 m along the north margins of the Porcupine Hills. Glacial Lake Westrup (Alley and Harris, 1974) was ponded in the Happy River valley area by Rocky Mountain ice to the north and Keewatin ice to the east in Willow Creek valley. The Laurentide provenance Maunsell Till and Rocky Mountain Maycroft Till were deposited by glacial ice during this episode. The Chain Lakes Clays and Silts were laid down in glacial Lake Westrup (Jackson, 1980).

Glacial Episode Three marks the last time Rocky Mountain provenance ice and Keewatin ice interacted in the study area. During this episode, ice originating in the Rocky Mountains within the study area and immediately to the northwest coalesced with and was diverted southward across the Foothills by Keewatin ice. The Keewatin ice was fronted by glacial ice diverted southward from Athabasca Valley. Two tills were deposited – the Bow Valley Till (Rutter, 1972) of exclusively Rocky Mountain provenance and the Erratics Train Till of mixed provenance (Jackson, 1980). During eastward retreat of glacial ice from the Foothills, proglacial lakes were ponded along the western margin of the ice. These lakes migrated with the retreating ice. The Sheep River Silts and Clays were deposited in these lakes.

Glacial Episode Four involved an advance of Keewatin ice to just east of the study area and advances of alpine glaciers which were restricted to the valleys of the Front Ranges. The Keewatin ice dammed Bow Valley which caused a lake to pond and back up into the southeast Calgary area. An age range of ca. 12 000 to 18 000 BP is estimated for the duration of Glacial Episodes Three and Four. The alpine Canmore advance reached the mountain front and was in retreat by about 12 000 BP. It was followed by the smaller Eisenhower Junction advance which was restricted to valleys along the Great Divide. Recent evidence to the north of the study area suggests that the Eisenhower Junction advance must have occurred prior to 10 000 BP (Luckman and Osborn, 1979). Only one Neoglacial advance which took place over the past several hundred years is recognized within the study area.

TERRAIN INVENTORY

Terrain units were defined and mapped on the basis of their genesis, surface form, and the processes which have modified or are currently modifying them. Terrain units described in detail in the text are summarized in Table 3. This summary should be laid along side the map for quick reference to physical properties and land use capabilities of terrain units. Definitions and descriptions of terrain units are based upon the observed characteristics of these units within the study area and are not intended to be all encompassing or universal in application.

In the course of discussing terrain units, relative erodibility of low, medium and high is assigned to the units. These terms are entirely qualitative and are based upon my observations of the consequences of disturbance of various terrain surficial materials and upon the qualitative methodology suggested by Rutter (1968). They refer to the expected consequences of denuding the deposit of vegetation.

A quantitative methodology for controlling gully erosion was developed by St-Onge (1978) for the erodible bedrock units of the Swan Hills. This methodology is likely applicable to nonstony deposits within the present study area. For general discussions of soil erodibility, the reader is directed to Bryan (1977) and Wischmeier (1976).

With respect to erodibility classifications used here, an area of low erosion hazard may only experience slight rilling with little loss of site productivity. A site of moderate erosion hazard would experience deeper rilling and some loss of ability to support vegetative cover. Sedimentation problems in adjacent streams or lakes might be anticipated if the disturbance covers a sufficient area. An area of high erosion hazard would experience extensive rilling and gullying down to parent material, and permanent loss of productivity. Sedimentation problems in adjacent streams and water bodies would be certain. It should be emphasized that erosion hazard is a complex product of variables such as soil cohesion, slope angle, slope length, rainfall intensity, soil moisture antecedent to rainfall, rainfall duration, and vegetative covering, to name only a few. The prime factor, however, is the care with which the disturbing activity is carried out with respect to erosion control. An area of low erosion potential can produce high yields of sediment if it is poorly managed.

Slopes in the study area strongly influence the deposits found on them and determine the processes which modify these deposits. For the purpose of terrain inventory, two slope categories, s_1 and s_2, are defined (Map 2-1984). The s_1 slopes are found throughout the Front Ranges and Eastern Main Ranges and locally in the more rugged areas of the Foothills. These slopes are characterized by a steep lower slope (>15°), covered by colluvium, fringed along the valley edge by alluvial and debris fans, and crowned by a steep to near vertical (>30°) scarp-line slope. This upper slope is largely bare rock and is a source area for rock falls, rockslides, debris flows, and snow avalanches which may routinely pass across the middle slope and construct the fan apron. The s_2 slopes are found throughout the Foothills, Porcupine Hills, parts of the Prairies, and less rugged areas of the Front Ranges. These slopes typically have angles of between 5° and 30° and are entirely or mostly covered by colluvial or glacial overburden. Slope processes are confined to fluvial erosion and sedimentation and soil creep with velocities imperceptible over short periods of observation.

Morainal deposits

Morainal deposits are highly unsorted sediments composed of boulder to clay size particles deposited by glacial ice. If modified at all by fluvial processes during or after deposition, modification is limited to the winnowing of fines without causing any major stratification of the deposit. Morainal deposits originate either by deposition, along the sole of the actively flowing glacier, of sediment eroded from the substrate by the shearing, abrasion, and plucking of the overlying ice, or by deposition of sediment accumulated within or on the surface of the glacier during deglaciation (Dreimanis, 1976).

For the purposes of this study, morainal deposits will be subdivided into three groups on the basis of texture: till, bouldery till, and coarse bouldery glacial rubble. The two latter deposits are restricted to high mountain valleys and will be discussed under their respective terrain units. Till is the most common morainal deposit along the low relief easternmost Foothills and Prairies where it forms a nearly continuous blanket over bedrock. Within the Foothills proper and mountains, till is found along valley floors and as a discontinuous cover on valley walls to varying elevations.

Texture of surface tills

Selected till samples from throughout the study area were chosen for complete grain size analyses over the interval $\leq$32 mm to $\leq$0.002 mm (-5ϕ to 9ϕ) at $\frac{1}{2}\phi$ intervals. The textures of surface tills of the study area are typically bimodal over this interval. This bimodality is characteristic of most tills (Dreimanis and Vagners, 1969, 1971). The coarse mode occurs between 32 and 2 mm and the fine mode between 2 mm and less than 0.002 mm. Table 4 shows computed values for means and standard deviations for weight percentages of till samples in the 32 mm to greater than 2 mm fraction. Tills within the Front Ranges and tills of the central Foothills and eastern Foothills which were deposited by ice exclusively originating in the Front Ranges are typically coarser than mixed provenance or Keewatin tills in the easternmost Foothills and Prairies. The larger content of coarser grain sizes (32 to > 2 mm) in tills of the central and eastern Foothills reflects the close proximity of the resistant carbonates of the Front Ranges and the short distance of transport of resistant clasts. Resistant coarse clasts carried by ice originating to the north or east of the study area, however, have travelled hundreds or thousands of kilometres from primary sources of resistant bedrock[1]. As expected, the contents of coarse resistant clasts in tills found in the easternmost Foothills and Prairies are relatively less than contents of coarse grain sizes in tills deposited by ice originating in the Front Ranges. Furthermore, the rugged relief of the Front Ranges and Foothills, the steeply dipping bedrock, and resistant rock units also favour the accumulation of coarse debris in the ice due to glacial plucking and quarrying (Flint, 1971, p. 113); this results in a stony till. Conversely, the flat lying easily erodible, argillaceous rocks and older Quaternary deposits traversed by ice entering the study area from the north and east yield more finely textured tills.

A mode in the greater than 32 mm size fraction occurs in some of the tills of the easternmost Foothills and Prairies and all of the tills of the Front Ranges and central Foothills. Particles greater than 32 mm in size may locally constitute up to 10% of tills in Front Ranges and Foothills but usually less than 1-2% in easternmost Foothills and Prairies. Local very stony tills occur in the easternmost Foothills and Prairies where tills appear to have been largely derived from pre-existing gravel deposits.

Figures 3A and 3B show cumulative frequency curves of size fractions less than or equal to 2 mm in size for surface till samples from the Front Ranges and Foothills (Fig. 3A) and the easternmost Foothills and Prairies (Fig. 3B). The curves only include samples for which complete sediment analyses were carried out by sieve and pipette methodologies. The curves show that tills found in the Front Ranges and Foothills generally contain more coarse sand size particles and less clay size ones than easternmost Foothills and Prairies tills and about the same cumulative percentages of fine sand and silt size particles. These observations are expressed more clearly in Figure 4 which shows mean cumulative frequency curves for both Front Ranges and Foothills tills and easternmost Foothills and Prairies tills. A histogram showing the mean and standard deviation in each size class of the two till groups is show below the curves. It should be noted that the clay size fraction does not represent another mode but is plotted in one size class due to the difficulty of dispersing clay size ($\leq$0.002 mm) particles.

Hydrometer analysis was used for determination of the percentages of sand, silt, and clay in most of the finer than 2 mm fractions of till samples because these percentages are adequate for most engineering and stratigraphic purposes and because of rapidity of the method. The textures of the tills of the study area fall into three groupings (Fig. 5). These are strongly influenced by the immediate bedrock provenance. Tills found in the easternmost Foothills and Prairies, where relief is low and bedrock is almost entirely composed of sandstone and shale, are dominantly silty clay, clay loam, and silty clay loam in texture. For those found in the Front Ranges, where relief is high and carbonate rocks, conglomerates, and quartzites are present as well as

[1] Some of these resistant rock types were likely derived from the reworking of older tills which were transversed by ice of Keewatin provenance.

Table 3. Summary of geotechnical properties, land use, and potential hazards of terrain units shown on Map 2-1984

Symbol	Unit Name	Geotechnical Data*	Current and Potential Land uses	Hydrologic Restrictions and Hazards
LS	Landslide deposit	Broken masses of bedrock	Variable, may be devoid of vegetation or support commercial forest; wildlife habitat, recreation.	May be active or subject to re-activation.
O	Organic deposit	USCS - OL to OH	Wildlife habitat, recreation.	High water content and low strength of deposits preclude most land uses.
Cb, Cv	Colluvial blankets and veneers on slopes of less than 5°	USCS - ML and CL soils	Commercial and non-commercial forest, scattered pasture, recreation, wildlife habitat.	Erosion and slope stability hazard low.
Cb_2, Cv_2	Colluvial blanket and veneer on s_2 slopes slopes	USCS - ML and CL soils	Commercial and non-commercial forest, scattered pasture, recreation, wildlife habitat.	Erosion hazard increases with slope.
Cb_1, Cv_1	Colluvial blanket ano veneer on s_1 slopes	USCS - ML, CL, GC, GM soils	Commercial and non-commercial forest, scattered pasture, recreation, wildlife habitat.	Erosion hazard generally high; slopes steep.
Cb_1 [A, Cv_1 [A	Colluvial blanket and veneer cut by avalanche chutes	USCS - ML, CL, GC, GM soils	Generally noncommercial forest, recreation, wildlife habitat.	Subject to invasion by avalanche of snow and rock.
bCv_1, bCb_1	Bouldery colluvial blanket and veneer on s_1 slopes.	USCS - GM to rock rubble	Wildlife habit, recreation, some pasture.	Steep slopes limit use of units.
cbCa	Coarse boulder colluvial apron	Rock rubble	Wildlife habitat.	Subject to rockfalls from adjacent cliffs. Constituent material at angle of repose.
Cf [A, Cf [W	Colluvial fan	USCS - GW, GM, ML soils	Commercial and non-commercial forest, recreation, wildlife habitat.	Subject to invasion by flood flow, avalanches, and mudflows.
cbCa [I	Rock glacier	Rock rubble	Wildlife habitat, recreation.	May be in slow motion and (or) subject to collapse.
cbCb [I	Colluvium modified by permafrost	Rock rubble	Wildlife habitat, recreation.	Underlain by documented or suspected permafrost.
Ap [W	Alluvial (flood) plain	USCS - GP, GW, SP, SW soil.	Wildlife habitat, recreation.	Subject to periodic flooding and lateral migration of streams.
At	Alluvial terrace deposit	USCS - GP, GW, SW, SP soils.	Source of sand and gravel; pasture; cultivated where capped by a sufficient covering of loess.	High permeability of deposit makes unit a poor location for storage of solid or liquid wastes.
Af [W	Alluvial fan deposit	USCS - GP-GM, SW-SM	Locally a source of sand and gravel, source of bulk fill, commercial and non-commercial forest, wildlife habitat, recreation.	May be subject to periodic flooding and (or) invasion by mud and debris flows and lateral migration of streams.

sandstones and shales, textures are dominantly silty loam and loam. Tills found in the Foothills, between these two provenances, display a wide range of textures between sandy loam and clay.

Colour

Tills of the study area usually vary in colour according to their provenance. Tills found in the Front Ranges and Foothills are typically light brownish grey, greyish brown, pale brown, and light grey (Munsell colours 10YR 5/2, 10YR 5/2, 10YR 6/3, 10YR 7/1). Tills found in the easternmost Foothills and Prairies have more yellowish hues of the same colour. The most common colours are light brownish grey, light grey, and greyish brown (2.5Y 6/2, 2.5Y 7/2, 2.5Y 5/2).

Atterberg limits

Sediments such as tills with a large component of fine particles of silt and clay sizes can exist in several physical states according to their water content. When dry, they behave as solids and will fracture when stressed past a given load. With the progressive addition of water they become increasingly plastic in behaviour until they flow like a liquid. The Atterberg limits are arbitrary boundaries at which semisolid, plastic, and liquid states are reached by a soil with the addition of water. The two Atterberg limits investigated in this study are the liquid limit (LL) and plastic limit (PL). The difference of these two values (LL - PL), known as the plasticity index (PI), indicates the range of water contents over which the soil behaves as a plastic material. Table 5 shows values of Atterberg limits compiled for tills from the

Table 3 (cont.)

Symbol	Unit Name	Geotechnical Data*	Current and Potential Land uses	Hydrologic Restrictions and Hazards
Gr, Gh, Gp	Ridged, hummocky, and planar glaciofluvial deposits	USCS – G and S soils.	Source of bulk fill aggregate and sand, depending on the texture of the deposit; pasture; planar deposits locally cultivated where thick loess deposits cap unit.	High permeability precludes storage of solid or liquid wastes; may locally be significant sites for groundwater recharge; hummocky and ridged deposits may require regrading for alternative uses.
Lm, Lb, Lv	Rolling glaciolacustrine plain, blanket, veneer	LL-32-66%; PI-12-45% USCS - MH to CH soils in the easternmost Foothills, ML to CL in the Foothills and Front Ranges. UCS - 152-310 kPa *† PR - 10-34 blows/30.5 m *† WD - 1923-2003 kg/m³ *† SPD - 1346-1715 kg/m³ *† POM - 22%	Forage crops or pasture in the Prairies, forested in the Foothills; suitable repository for solid or liquid waste and source for bulk impervious fill.	Erosion hazard generally low to nil; expansive potential high; slope stability problems nil except along canyons; unimproved roads impassable in wet weather.
Lp	Glaciolacustrine plain	Similar to glaciolacustrine deposits except UCS lower, PR lower, and WD less. May contain organic material.	Pasture and wildlife, habitat; may be cultivated on rare well drained sites.	Erosion hazard low to nil; slope stability problems nil; may be flooded during wet years; alternative land uses restricted due to the low strength of the material.
Lh	Hummocky, glaciolacustrine deposit	Similar to those above, may contain some interstratified gravels and grade into till.	Pasture and wildlife habitat.	Few possible alternative land uses without extensive regrading and draining.
Mm, Mb, Mv	Rolling morainal plain, blanket, veneer	LL-30-42%†; PI-15-25%† USCS - ML and CL soils UCS - 75-283 kPa *† PR - 31-35 blows/30.5 cm *† WD - 2112-2144 kg/m³ *† SPD - 1693-1952 kg/m³ *† POM - 12-18% *†	Cultivated or used for pasture; suitable repository for liquid or solid waste due to low permeability.	Erosion hazard low to nil except for wind erosion in cultivated areas; slope stability problems nil except along steep canyon sides or gullies; expansivity hazard low to moderate.
Mh	Hummocky moraine	Probably in the ranges shown above.	Pasture and wildlife refuge; locally important for groundwater recharge.	Most alternative land uses would require regrading and draining of the unit.
bM, Mr, bcMr	Bouldery till and ridged morainal deposits	Stony, low in plasticity, probably high UCS, high PR, and higher WD than those above.	Recreation, wildlife habitat.	Rugged topography and high elevation restrict most land uses.
rMh	Coarse bouldery glacial rubble	Bedrock rubble, no fines.	Recreation, wildlife habitat.	Rugged topography and high elevation restrict most land uses.

* LL – liquid limit, PI – plasticity index, USCS – Unified Soil Classification System, UCS – unconfined compressive strength, PR – penetration resistance, WD – wet density, SPD – standard Proctor density, POM – Proctor optimum moisture content.
* Values for easternmost Foothills and Prairies only.
† Minimum and maximum values.

Table 4. Mean weight per cent and related statistics of the coarse (32 to >2 mm) fraction of surface tills of the study area

Tills Sampled	$\bar{X}$	s	n	max.	min.
Foothills tills having origins in in the Front Ranges (Bow Valley equivalent and Maycroft tills; Jackson, 1980)	40.00	14.61	27	68.16	10.44
Front Range origin till in easternmost Foothills and Prairies (Bow Valley Till; Jackson, 1980)	21.28	10.49	12	38.31	7.28
Mixed provenance till and Laurentide till in easternmost Foothills and Prairies (Erratics Train and Maunsell tills; Jackson, 1980)	12.41	14.44	36	36.62	0.31

Front Ranges, Foothills, and easternmost Foothills and Prairies sampled during this study. Table 6 lists values compiled from unpublished geotechnical investigations.

Plasticity index values of the tills of the study area range from low for tills found in the Front Ranges to low and intermediate for tills found in the Foothills and Prairies, that is, Front Ranges tills are plastic over a very small range of moisture contents whereas Foothills and Prairie tills are plastic over a larger range. The dominant controlling factor governing the plasticity indexes of these tills, regardless of age, appears to be the clay mineralogy of the underlying bedrock. Figure 6 shows a plot of plasticity index versus liquid limit for till samples from the Front Ranges and from the Foothills and Prairies. The "A line" in the diagram is an empirical line. It has been found that soils (in the engineering sense) of any given provenance generally plot

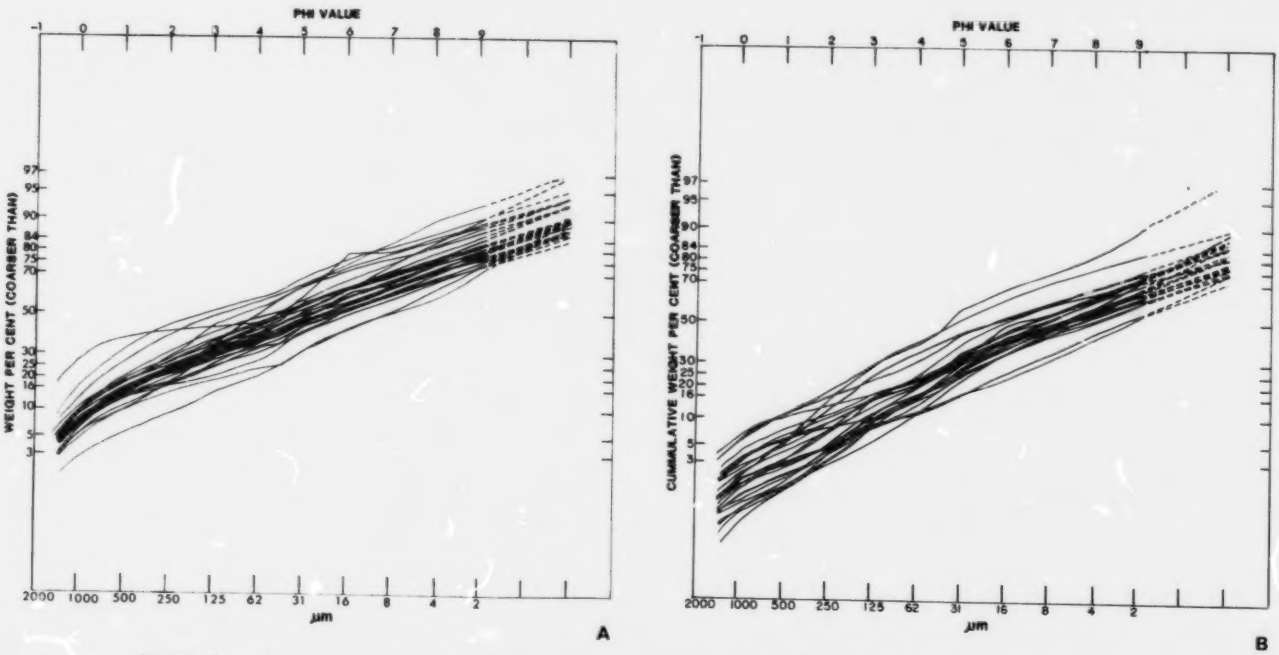

Figure 3. Cumulative weight per cent plots of textural size ranges of surface tills of the study area. Tills from the Front Ranges and Foothills (3A) generally are coarser than those found in the easternmost Foothills and Prairies (3B) due to the presence of more resistant rock types and rugged topography in the former.

parallel or subparallel to the A line (Terzaghi and Peck, 1967, p. 34). The vertical dashed line separates silts and clays of low plasticity from silts and clays of high plasticity. A "t test" of the plasticity index values of tills of the Front Ranges and of the Foothills and Prairies indicated that the means of the two groups do not represent the same population. This apparent control of till plasticity by bedrock provenance indicates that much of the fine fraction of the tills of the study area was derived locally and that the fine fraction changes rapidly in character from one bedrock province to another. This agrees with the conclusions reached with respect to changes in till texture and bedrock provenance. The Atterberg values of the tills of the easternmost Foothills and Prairies are approximately the same as those of the surface tills on the Prairies to the east of the study area found by Pawluk and Bayrock (1969) and probably reflects the similarity of bedrock in the two areas.

Unified Soil Classification

Due to their stony texture and low plasticities, tills found in the Front Ranges and Foothills are classified as SM or ML soils under the Unified Soil Classification Scheme (Wagner, 1957) depending upon their stoniness. The less stony tills of the eastern Foothills are more clayey and of low to intermediate plasticity and range from ML to CL and MI to CI soils. Classes have been determined only for those samples for which Atterberg limits were available.

Clay mineralogy

Clay minerals are colloidal-like (usually $\leq$0.002 mm) crystalline particles composed of sheet-like molecules of alternating silicon-oxygen and aluminum oxygen layers (e.g., Grim, 1968). Clay-size minerals are fragments of nonclay minerals or nonclay minerals precipitated in the clay

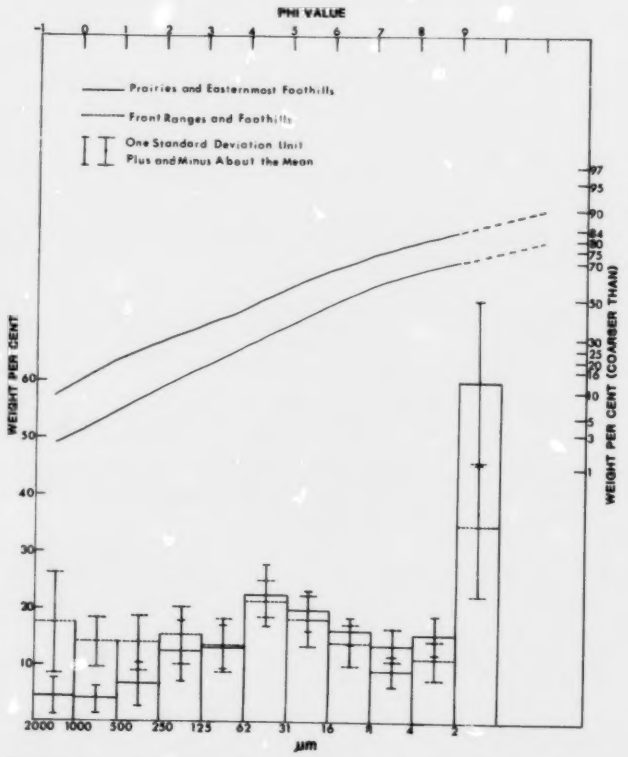
PHI VALUE
Prairies and Easternmost Foothills
Front Ranges and Foothills
One Standard Deviation Unit
Plus and Minus About the Mean
WEIGHT PER CENT
WEIGHT PER CENT (COARSER THAN)
2000 1000 500 250 125 62 31 16 8 4 2
µm

Figure 4. Mean cumulative weight per cent textural curves for surface tills plotted in Figure 3 and histograms showing compositional differences in each size class between tills of the Front Ranges and Foothills and Prairies and easternmost Foothills.

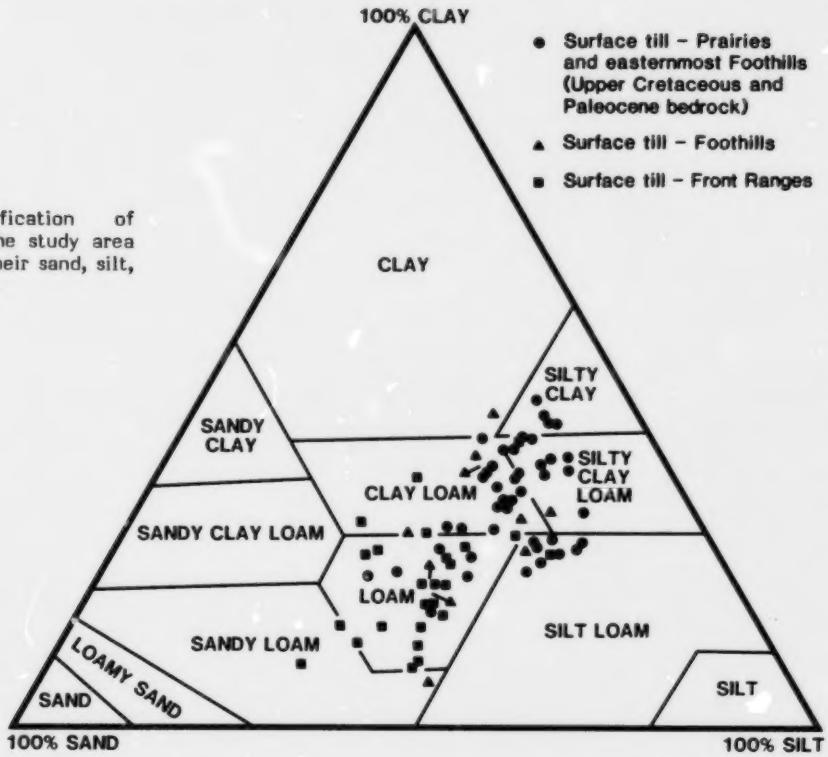

Figure 5

Textural classification of surface tills of the study area on the basis of their sand, silt, and clay contents.

Table 5. Atterberg limits of sampled tills of the study area

	Plastic limit					Liquid limit				Plasticity index			
Location	$\bar{X}$	n	s	max.	min.	$\bar{X}$	s	max.	min.	$\bar{X}$	s	max.	min.
Front Ranges	13.9	19	2.9	20.3	10.0	19.4	4.9	25.9	13.6	5.5	3.1	12.1	1.7
Foothills	17.2	8	2.6	18.9	11.2	29.6	5.3	37.4	20.9	12.0	4.1	18.5	6.8
Easternmost Foothills and Prairies	16.8	21	3.8	21.6	16.1	34.0	4.9	43.1	24.2	15.3	4.4	22.6	7.0

size range. Both clay and clay-size minerals influence the physical and chemical properties of surficial sediments such as till. Identification of the types of minerals present permits understanding and prediction of the chemical and physical properties of the sediment being studied.

The mineralogy of the $\leq$0.002 mm fractions of 16 till samples from widely separated locations throughout the study area were determined through X-ray diffraction analysis. Details of laboratory methods used are provided in Appendix 1. Figure 7 shows sample X-ray diffractograms obtained from these samples. Percentages of clay and clay-size minerals determined by X-ray diffraction analysis are semi-quantitative estimates.

Two general clay mineral provinces were found in the tills. These provinces reflect the clay mineralogy of subjacent or adjacent bedrock assemblages (Table 7). Clay minerals of the easternmost Foothills and Prairies clay province make up well over 50% of clay size particles with the remainder composed of quartz and carbonate minerals. The clay minerals are predominantly kaolinite, chlorite, montmorillonite, and a 10Å mica referred to for convenience as illite. The presence of montmorillonite reflects the extensive content of bentonitic shales in the Upper Cretaceous and Paleocene clastics which make up much of the easternmost Foothills and adjacent Prairies (Babet, 1966).

Kodama and Brydon (1966) studied clays obtained from tills and glaciolacustrine deposits derived from Upper Cretaceous shales and sandstones throughout the Prairie Provinces. They found the illite and montmorillonite peaks on X-ray diffractograms to represent a single randomly mixed layer, dioctahedral clay mineral with structure randomly alternating between mica and montmorillonite. Since the tills of the easternmost Foothills and Prairies appear to be largely derived from the same Upper Cretaceous and similar Paleocene strata as those units which underlie the Quaternary sediments studied by Kodama and Brydon, the same mixed layer clay mineral should be present. Thus, the content of illite and montmorillonite in Table 7 should be

Table 6. Survey of engineering properties of surface tills from pre-existing exploratory foundation borings[1]

A. Easternmost Foothills and Prairies

	South Calgary Area[2,3] (Erratics Train Till)					Priddis Area[4] (Bow Valley Till)					Quirk Creek Gas Plant[5] (Bow Valley Till)					Chain Lakes Reservoir[6] North Dam (Erractics Train Till)					Chain Lakes Reservoir[6] South Dam (Maycroft Till)				
	$\bar{X}$	s	n	max.	min.	$\bar{X}$	s	n	max.	min.	$\bar{X}$	s	n	max.	min.	$\bar{X}$	s	n	max.	min.	$\bar{X}$	s	n	max.	min.
Penetration resistance, by standard penetration test[7] (blows per foot, 30.5 cm)	35	14.5	40	75	17	-	-	-	-	-	31	9.4	42	53	16	-	-	-	-	-	-	-	-	-	-
Unconfined compressive strength (kPa)	214	-	6	283	75	-	-	-	-	-	269	152	10	621	124	241	-	4	290	145	297	-	6	286	241
In situ moisture content (% dry weight)	16	3	36	21	17	15	1.6	31	27	11	19[8]	5.9	83	33[8]	13[8]	18	-	46	25	8	15	-	85	24	3
Atterberg limits (% dry weight)																									
Liquid limit	33	6	26	46	20	-	-	-	-	-	-	-	-	-	-	42	-	14	52	34	30	-	36	36	19
Plastic limit	16	2	26	22	14	-	-	-	-	-	21	-	2	25	17	17	-	14	-	-	15		36	-	-
Plasticity index	17	5	26	27	5	18	4.0	25	22.9	8.3	-	-	-	-	-	25	-	14	32	18	15	-	36	24	3
Wet density (kg/m^3)	2128	-	3	2112	2144	-	-	-	-	-	-	-	-	-	-	2064[9]	50	25	2161	1919	2147[9]	36.8	19	2192[9]	2032[9]
Standard Proctor maximum dry density (kg/m^3)	-	-	-	-	-	1840	65	25	1952	1693	-	-	-	-	-	-	-	-	-	-	1952	-	1	-	-
Optimum moisture content (% dry weight)	-	-	-	-	-	18	4.6	31	19	13	-	-	-	-	-	-	-	-	-	-	12	-	1	-	-

B. Kananaskis valley, Front Ranges[4,9]

	$\bar{X}$	s	n	max.	min.
In situ moisture content (% dry weight)	11	3.9	15	15	5
Plasticity index (% dry weight)	7.4	-	22	11.4	4.0
In situ density (kg/m^3)	-	-	2	2065	1935
Standard Proctor maximum dry density (kg/m^3)	125 2016	5.0 81	18 18	131 2113	118 1823
Optimum moisture content (% dry weight)	9	2.7	18	15	6

$\bar{X}$ = arithmetic mean; s = standard deviation;
n = number of samples; max. = maximum value; min. = minimum value

1 Till may be directly at surface or beneath loess, glaciolacustrine, or fluvial deposits; values not available are left blank in the table.
2 South of 51°N; sampling grid: one sample for about every 0.9 km^2 or where available in areas of sparse data. Data courtesy of the City of Calgary.
3 Source for South Calgary data: borings for Glenmore Village and Pentecostal Tabernacle; courtesy of R.M. Hardy and Associates, Calgary.
4 Data courtesy Alberta Transport,
5 Data courtesy Imperial Oil Ltd.,
6 Data courtesy Prairie Farm Rehabilitation Administration,
7 Test consists of driving a standard sampling spoon into the soil by dropping a 140 lb. (63.6 kg) weight from a height of 30 inches (72.6 cm). Data courtesy of the city of Calgary.
8 Values estimated from points plotted on borehole logs.
9 Exploratory borings, Kananaskis Road; 51°N to 10 miles south in Kananaskis valley.

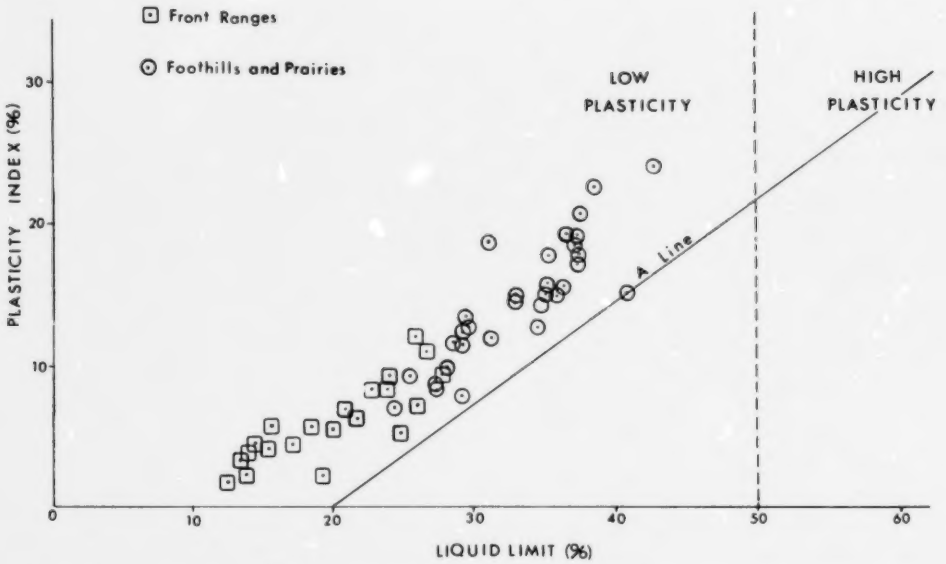

Figure 6. Plasticity index vs. liquid limit for surface tills of the study area. Tills from the Foothills and Prairies are of low to intermediate plasticity whereas those from the Front Ranges have very low plasticity values.

regarded as estimates of their abundances as mixed layers within a single clay species. The montmorillonite content of tills is observed to decrease westward into the Foothills (e.g., 72274S3, 24675H7, 73074E2, and 82174H1 in Table 6 and 24675H7 and 72274S3 in Figure 7) with the increase in outcrop area of essentially nonbentonite-bearing Lower Cretaceous and Upper Jurassic sediments. The micaceous minerals in these older units, for example the Kootenay Formation, have not been investigated in detail. Clay size minerals in Front Range tills (Fig. 7, Table 7, sample 7974K3) are typically composed of well over 50% finely ground nonclay minerals. The clay minerals kaolinite and illite dominate with variable amounts of chlorite present.

The large percentage of nonclay minerals in the clay size fraction of Front Range tills probably results in the very low plasticities which are characteristic of these units (Fig. 6). Conversely, the higher contents of clay minerals in the clay size fractions of Foothills tills probably account for the higher plasticity values of these units.

Expansiveness

Montmorillonite and other expandable clays have the property of incorporating water and other polar liquids such as ethylene glycol into their lattices with a resulting change in volume and significant swelling pressures. Little work has been done in and around the study area to investigate swelling pressures in tills with appreciable contents of expanding clays. The only testing to measure swelling pressures in surficial deposits in the study area has been carried out on glaciolacustrine sediments as part of a foundation study for the Quirk Creek Gas Plant. Results are detailed in the subsequent discussion of glaciolacustrine deposits. Law (1971) investigated a method for the prediction of heave from expansive clayey soils by field and laboratory investigation of the surface till at the University of Lethbridge. Law found heaving to be directly proportional to in situ dry density and inversely proportional to in situ moisture content.

Table 7. Estimates of abundances of clay minerals and clay-size minerals in tills of the study area (values in %)

Sample Number	Quartz	Feldspar	Calcite	Dolomite	Kaolinite	Illite	Chlorite	Montmorillonite
Front Ranges and Foothills								
7974K3	13	-	76	5	-	6	Tr	-
61074K1	17	Tr	45	24	Tr	14	-	-
86743P6	10	-	30	16	20	24	Tr	-
7875H2	15	7	7	Tr	21	42	8	-
Easternmost Foothills and Prairies								
72274S3	16	9	Tr	Tr	27	48	-	-
73074E2	19	10	7	5	23	23	12	Tr
82174H1	22	6	Tr	-	37	35	-	-
13575F3	22	-	27	3	15	12	7	14
13575P4	14	-	6	Tr	27	26	14	11
27575T1	12	5	6	Tr	21	27	18	9
20575T3	15	6	8	3	18	28	9	12
21575S1A	17	11	5	Tr	21	23	9	11
5675S1	16	5	15	Tr	10	38	6	10
24675H7	15	8	7	Tr	19	41	9	-
11675H7	27	5	6	Tr	17	25	8	11
2775M2	19	Tr	14	Tr	22	20	10	16

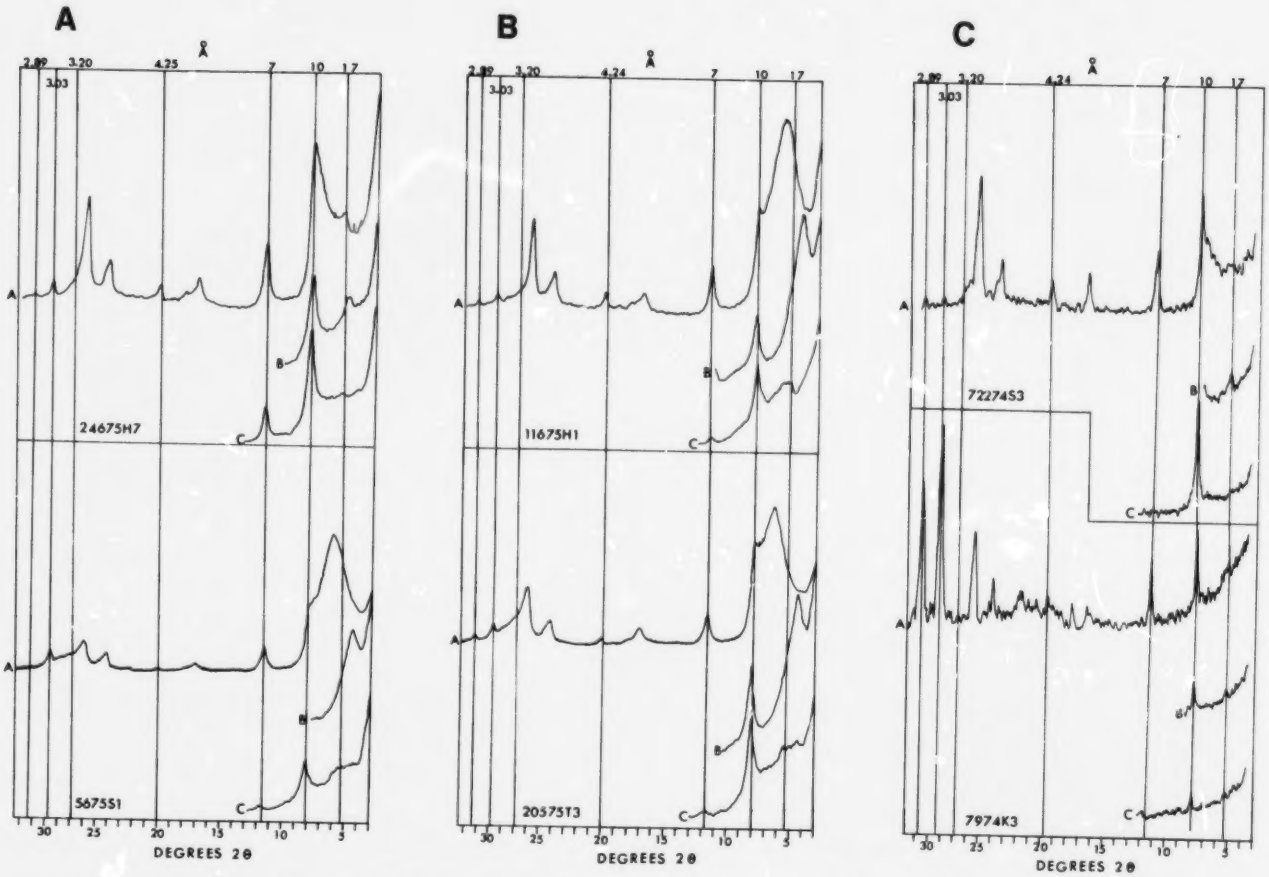

Figure 7. Representative X-ray diffractograms of clay size fractions (<0.002 mm) of tills of the study area. Samples 11675H1, 20575T3, 24675H7, and 5675S1 were taken from tills in the easternmost Foothills and Prairies whereas Samples 7227453 and 7974K3 were taken from tills in the Foothills and Front Ranges, respectively. (A) specimens untreated, (B) specimens glycolated, (C) specimens heated to 550°C.

Williams (1957) devised an empirical method for determining relative expansiveness of soils based upon the clay activity of the soil (Skempton, 1953). Clay activity is the quotient of the plasticity index of a soil divided by the weight per cent clay content. Since the clay mineralogy largely determines at what moisture contents a soil passes through its plastic and liquid limits, it follows that soils of similar clay mineralogy and attendant expansivity should have the same activities, i.e. plot along a straight line. Figure 8 shows a plot of clay activities of tills of the easternmost Foothills and Prairies of the study area. The low, medium, high, and very high expansiveness boundaries are after Williams (1957). The dashed envelope encloses values determined by Law at Lethbridge. Although most values from the study area are low to medium, several samples have values in the very high range. Direct application of Law's heave values to the tills of the study area should not be made; however the tills in both areas are dominantly derived from similar bedrock units and could be expected to be at least comparable in their physical properties. Thus, it may be concluded that significant heaving from swelling clays is a possibility at sites in the easternmost Foothills and Prairies of the study area where alteration of surface and subsurface drainage would significantly increase the moisture contents of surface tills. If man-made structures confine the resulting heaving, significant deformation of the structure may occur.

Moisture content

In situ moisture contents of surface tills are available for only four areas within the study area: Kananaskis Valley, south Calgary area, Priddis area, and Chain Lakes Reservoir area (Table 6). The values compiled were all obtained from exploratory borings below the zone of seasonal moisture variation. Atterberg limits of samples analyzed for the present study (Table 5) plus those collected from previous studies (Table 6) show moisture contents of tills to be typically at or below the plastic limit. Such a range of moisture contents indicates that the tills of the study area are typically stiff to slightly plastic in situ.

Compressive strength and penetration resistance

Table 6 lists values of unconfined compressive strengths of surface tills of the study area. Unconfined compressive strength data are scarce in the study area as indicated in Table 6.

The observed variations between maximum and minimum values of compressive strength at a given site may be the result of one, two, or all of the following factors: sampling disturbance, stress history, and postdepositional alteration. The lack of extensive compressive strength and consolidation testing data prevents determination of the degree to which each of these factors has affected values for unconfined compressive strengths of tills in the study area.

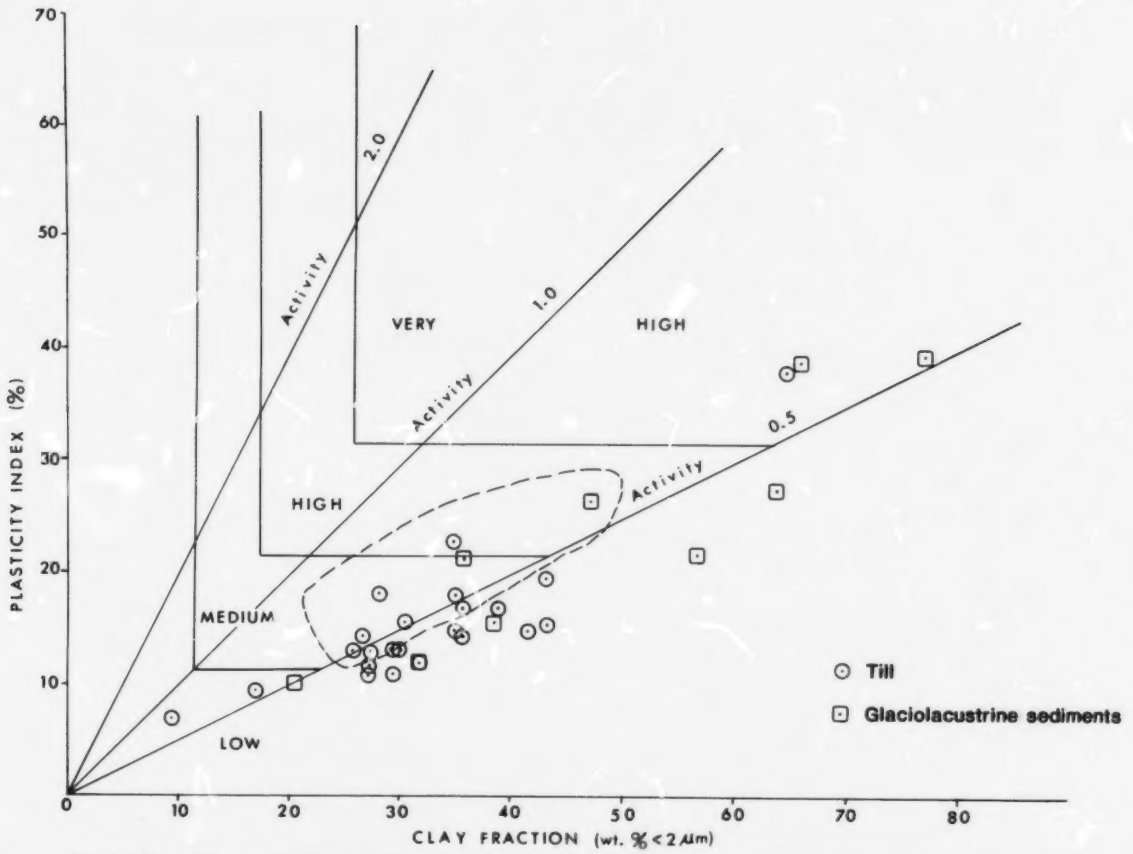

Figure 8. Clay activities of till and glaciolacustrine sediments of the study area and evaluation of the relative expansion potential. The area bounded by the dashed line indicates the limits of values determined by Law (1971) for till in the Lethbridge area.

Penetration resistance has been shown to have an approximate direct variability with unconfined compressive strength in clays (e.g., Terzaghi and Peck, 1967, p. 347). Such relationships, however, probably have little meaning for tills of the study area. The presence of gravel and larger clasts in the till probably is responsible for the large range in penetration values in Table 6. One value of 125 blows per foot (30.5 cm) in the south Calgary area was not included in the tabulation because it was in excess of typical values for shale bedrock in that area and was probably the result of interception of a large boulder size clast by the penetrometer. The penetration data in Table 6 do have some value in that they provide a characteristic range for penetration resistance associated with tills in the easternmost Foothills and Prairies. Tills in the Foothills and Front Ranges probably would have larger mean penetration resistances due to their typically greater contents of gravel and larger size clasts.

Standard Proctor and in situ densities

The amount of any soil that can be compacted into a given volume is a complex product of the type of moisture content, compacting technique, amount of energy applied, soil chemistry, and temperature (Lambe, 1958). For a given set of chemical and environmental factors, the compacting force, the manner of its application, and the moisture content of the soil being compacted become the dominant variables. The maximum density and attendant moisture content for a given compactive technique and effort is said to be optimum. Moisture contents above and below this value are said to be wet and dry of optimum, respectively. Many types of laboratory and field compactions tests have been used in this study. The one single test for which there are the most data in the study area is the Standard Proctor test which is used extensively by Alberta Transport. Standard Proctor values are useful as indexes which can be applied to the improvement of strength characteristic of soils to be used in various types of earth fills such as highway grades and earth dams.

Standard Proctor values from boreholes along the first 8 km of road between the Highway 22 curve near Priddis and Bragg Creek (Table 6) indicate a mean Proctor density of 1840 kg/m^3 with an accompanying average optimum moisture content of 18%. Only one Standard Proctor value is available from the south dam site, a dry density of 1952 kg/m^3 after compaction at 12% moisture content. As detailed above, surface tills from the eastern Foothills, for which data are available, have in situ moisture contents of 19% or less. If these values are taken as typical, then it appears that the surface tills in the easternmost Foothills and Prairies characteristically have dry of optimum Proctor moisture contents in situ.

Figure 9 shows a plot of plasticity index versus maximum Proctor dry density and optimum moisture content for values from the surface tills in the Priddis area and south Chain Lakes dam site. The significant negative correlation

(r = -0.73) between plasticity index and Proctor maximum dry density and the positive correlation (r = 0.77) between the optimum moisture content and plasticity index probably result from the interaction of several interrelated fractors. First, as previously discussed, clay mineralogy of the easternmost Foothills and Prairie tills is determined by similar parent bedrock units. With clay mineralogy almost constant, the similar values for clay activity for easternmost Foothills and Prairie tills probably indicates similar soil chemistry conditions (e.g. exchangeable cation, pH, electrolyte concentration). Consequently, the maximum dry density and the optimum moisture content should decrease and increase, respectively, with increasing clay content in the tills (Lambe, 1958). Although clay content is not available for the Standard Proctor values plotted, plasticity index values which have a strong linear relationship with clay content are available. Consequently, these plots should be useful for predicting Proctor maximum dry density and optimum moisture content for tills in the eastern Foothills and Prairies.

Maximum dry density values from Kananaskis Valley appear to be significantly larger than those from the easternmost Foothills and Prairies with attendant lower values in optimum moisture content. This is due to the smaller percentages of clay size particles in the Kananaskis Valley tills and the lack of expansive clays in these tills. No data are available for Foothills tills; however, values from both the Foothills and Front Ranges would be expected generally to exceed those of the easternmost Foothills and Prairies.

In situ wet density data for surface tills are available for only a few locations in the study area. These values (Table 6) indicate a variation between 1919 and 2161 kg/m^3.

Topographic form and mapped terrain units

Rolling morainal plain (Mm)

Rolling morainal plain and morainal blanket designations together comprise what is generally referred to as ground moraine or till plain. These units are composed almost entirely of till. Areas of rolling morainal plain are restricted to the broad valleys of the easternmost Foothills and Prairies principally in the area of and downstream from the confluence of Highwood River and Pekisko Creek (Map 2-1984). In this and similar areas, the surface till is of sufficient thickness (here about 2 to 12 m) and/or underlying bedrock is of sufficiently low relief that the surface relief is almost entirely developed upon the till. The topography developed on the morainal plain appears to be flat or gently undulating to the observer on the ground. From the air (Fig. 10) two main components can be seen: (1) small elongate enclosed depressions with diameters in the tens of metres, depths of 2 or 3 m, and spacings of tens of metres and (2) low sinuous ridges with vertical dimensions of 1 or 2 m and widths of perhaps 10 m and distances of separation in the tens of metres. The enclosed elongate depressions typically contain marshy vegetation, organic and inorganic silts and clays, and occasionally water. These depressions are usually in a northeast-southwest orientation and lie within large scale grooves on the ground moraine which indicate the trend of the last movement of ice in the area. Locally, these grooves are narrow with a wave length of about 100 m. The low sinuous ridges are generally oriented in the northeast-southwest direction but may range up to 90° from this bearing. Roadcuts through the ridges reveal them to be composed of till. Their general alignment appears to favour an origin as a crevasse filling or similar ablation origin (e.g., Prest, 1968 and Stalker, 1960b). Scattered deposits of sand and gravel are found locally on rolling moraine without any relict channels or apparent source of supply. These

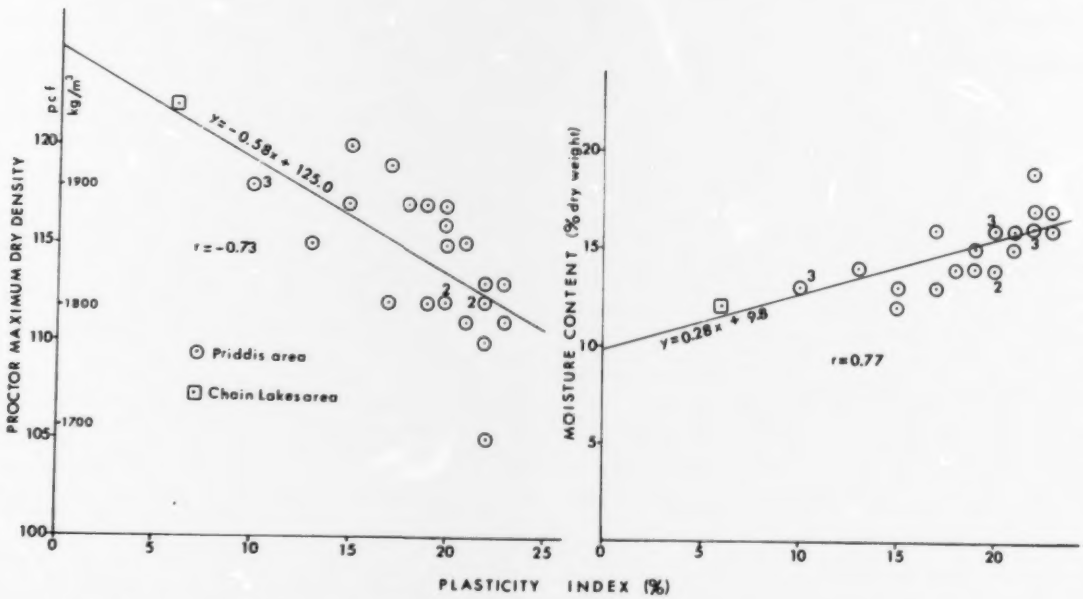

Figure 9. Proctor maximum dry density and moisture content vs. plasticity index for samples obtained from highway borings in the easternmost Foothills and Prairies of the study area. Lines are least squares regression lines. The correlation coefficient "r" is given in each plot. Where two or more samples yielded the same values, the number of identical values plotted at that point is shown.

Figure 10. Rolling moraine and kame features adjacent to Highwood River in the Prairies of the study area (tp. 18, rge. 1, W 5th mer.). Straight lines parallel and are adjacent to elongate depressions. "D" marks an area of sinuous till cored ridges. A large kame is outlined near the southwest corner of the photo. NAPL A18306-13

deposits probably originated on top of stagnant ice and were subsequently let down as the ice ablated. Rolling till plain deposits are commonly veneered by a discontinuous capping of silty loess which may be up to 1 m thick. This loess commonly overlies buried soils and contains tephra of mid Holocene age (ca. 6600 years old). A period of dry climate and attendant edaphic instability appear to have led to extensive eolian erosion and deposition during this period (Waters, 1979).

Modifying surficial processes. Fluvial erosion hazards and slope stability problems are negligible on rolling morainal plains due to their low relief. Exceptions can occur along streambanks or stream-marginal gullies. Drainage should be diverted from these areas in order to prevent headward gully growth and saturation of valley walls which might lead to slope instability. Wind erosion potential is low in cultivated areas if proper management techniques are employed.

Vegetation and land use. Rolling morainal plains are typically cultivated or are used for pasture. Only the stoniness of the soil and high water table conditions in kettle depressions pose limitations for agricultural use. The low permeability of the silty and clayey till composing this unit make it a poor source of groundwater and groundwater recharge except perhaps where joints or fissures are encountered. The low permeability of this unit makes it a desirable location for solid or liquid waste repositories. Conversely, its low permeability and large silt and clay content typically make unimproved roads and trails impassable during or after rain storms or during spring snow melt. Other properties of this unit as a foundation substrate or engineering material were discussed in the previous section on engineering properties of till.

Morainal blanket (Mb) and morainal veneer (Mv)

Morainal blanket is a continuous or nearly continuous covering of till and minor glaciofluvial and glaciolacustrine deposits usually several metres in thickness. It closely mirrors the topography of the underlying bedrock. Most of the morainal deposits in the easternmost Foothills and Prairies fall within this category due to the hilliness of the region and thinness of the overlying till mantle. In the Foothills and Front Ranges, till blankets are primarily confined to valley bottoms. On valley sides, till has been largely removed by erosion or reworked into colluvium, or may not have been present to begin with. In such areas where till is present as discontinuous patches, the term morainal veneer is used.

Modifying surficial processes. The degree to which degradational processes have and are modifying morainal blankets and veneers is dominantly a function at the sequences of the slope being mantled and the slope profile (see Map 2-1984). On slopes with average inclinations of less than 5°, (Mb) erosion hazards and slope stability problems are small to negligible and can be compared to rolling morainal plains in this respect. Morainal blankets or veneers with inclinations greater than 5° but situated on Foothills slopes (Mb_2) steadily increase from low to high in erosion hazard. At some locations, such as the valley walls along the north end of Spray Lakes Reservoir (Map 2-1984), nearly parallel ravines have been cut into the morainal blanket. These ravines are separated by several kilometres and have widths and depths measured in tens of metres. The symbol Mb [E is used for these and similar deposits.

Slope stability problems also increase with increasing slope. The commonly planar contact between the morainal blanket or veneer and the underlying bedrock may act as a ready failure plane on steeper slopes where such factors as seepage and leaching of cementing media reduce the factor of safety. Failure within the bedrock itself on steeper slopes, however, appears to be responsible for almost all large (discernible on 1:30 000 scale airphotos) slope failures on Foothills (Rs_2) slopes. Creep of slope deposits becomes more significant with increasing slope (Schumn, 1967; Harris, 1971, 1973). Morainal blanket and veneer deposits on mountain (Mb_1, Mv_1) slopes are subject to slope stability problems similar to those of Foothills (Mb_2, Mv_2) slopes; however, these former slopes have the additional hazard of periodic erosion or burial by rapidly moving mass wasting processes, such as rock and snow avalanches and mudflows, which periodically descend from adjacent precipitous bedrock slopes or vertical rock faces. Areas of morainal blanket or veneer presently cut by avalanche chutes are designated by the activity modifier [A on Map 2-1984. However, the possibility of alteration of all slope deposits by mass wasting phenomena such as snow or rock avalanches exists on all slopes bearing a "1" subscript.

Vegetation and land use. Morainal blanket deposits in the easternmost Foothills and Prairies generally floor broad stream valleys and are typically under cultivation or used for pasture. Morainal veneer deposits typically mantle the steeper hillsides and tops in this area, along with colluvial deposits, and are typically used for pasture lands but are not cultivated. Westward into the Foothills, morainal blankets are typically confined to valley bottoms (for example Sheep River valley near Gorge Creek) where they have been locally cleared of tree cover for pasture. Areas of morainal veneer in the central Foothills are typically forested (white spruce and lodgepole pine). In the Front Ranges, forest cover dominates but some grazing is afforded in parklands. The generally low permeability of morainal blanket deposits makes them good substrates for water holding facilities and solid waste repositories. Their low permeabilities preclude importance as groundwater recharge areas or aquifers and make such deposits poor substrates for unimproved roads. In upland areas, steepness of morainal blankets and veneers, and modifying processes such as avalanching, probably act as checks to most types of nonrecreational land use with the exception of timber harvesting and coal exploration.

Hummocky moraine (Mh)

Hummocky moraine is characterized by closely spaced rounded hummocks and enclosed depressions or kettles containing organic and inorganic silts and clays, marshy vegetation, and frequently open water (Prest, 1968; Stalker, 1973, p. 28). Relief from hummock top to kettle bottom ranges from a few metres at the edge of areas of hummocky moraine to 10 m or greater in more central parts of the moraine. Two distinct types of hummocky moraines are found in the study area: (1) coarse bouldery hummocky moraine (cbMh) found in valley bottoms in the Front Ranges and (2) silty clayey hummocky moraine (scMh) found in the eastern third of the study area around local uplands. The coarse bouldery hummocky moraine appears to have had an origin from the letting down of coarse debris from the surface of stagnating ice. Accumulation of such debris is common on the surface of ice in mountain areas where rock avalanches from precipitous slopes rain down upon adjacent valley glaciers. Coarse bouldery hummocky moraine deposits are prominent in the valleys of Owl Creek and Bryant Creek below Marvel Lake in the northwest corner of the study area. Relief on this moraine ranges between 10 and 20 m. The hummocky moraine found in the eastern third of the study area is similar to that described by Stalker (1960a, 1973) in the Red Deer-Stettler area and Drumheller area in that: (1) the hummocky moraine is predominantly composed of nonstratified loamy till similar to surrounding nonhummocky deposits except for its much greater thickness and (2) the hummocky moraine is typically found around or upon local uplands. Hummocky moraine north and east of the confluence of Sheep River and Three Point Creek and in the headwaters regions of Mosquito and Cross creeks are good examples (Fig. 11).

Modifying surficial processes. Erosion hazard and slope stability problems are of little concern within hummocky moraine areas of both the mountains and easternmost Foothills and Prairies due to the shortness and gentleness of most slopes. If sediment is eroded, it is typically transported only as far as the nearest kettle pond. Hummocky moraine in mountain areas (where it abuts against mountain slopes) may be encroached upon by talus slopes or colluvial fans.

Vegetation and land use. Hummocky moraine in the easternmost Foothills and Prairies is typically grass covered and utilized for pasture due to the difficulties presented for cultivation. Construction of roads or buildings in these areas requires extensive regrading, drainage of kettle lakes, and excavation of the low strength organic and inorganic silts and clays flooring them. Although generally low in permeability, hummocky moraine areas in the eastern third of the study area are locally important groundwater recharge areas due to their internal drainage pattern (e.g. areas of hummocky moraine in the Mosquito Creek basin). Springs abound in these areas and are locally important sources of water for livestock and some ranch houses. The small kettle lakes are also habitat for water fowl. Hummocky moraine may also contain some deposits of glaciofluvial gravels of various degrees of sorting. Deposits of clean sands and gravels are usually rare. Coarse bouldery hummocky moraine in the Front Ranges is typically forested and is largely located within Banff National Park.

Coarse bouldery glacial rubble (rMh)

These deposits are primarily composed of angular bedrock blocks, predominantly greater than 1 m in longest dimension. Individual blocks may reach up to 5 m or more in longest dimensions in some deposits. Smaller blocks plus sand and silt size sediments may be found between rubble blocks, but the deposit is entirely block supported. Glacial rubble deposits are primarily found in the higher mountain regions of the study area on valley floors and in or near cirques (Fig. 12). The rubble-like nature of these deposits, along with their occurrence as isolated heaps, appears to indicate a complex origin. Their coarseness suggests a primary origin as a rockslide or rockfall. The fact that these deposits

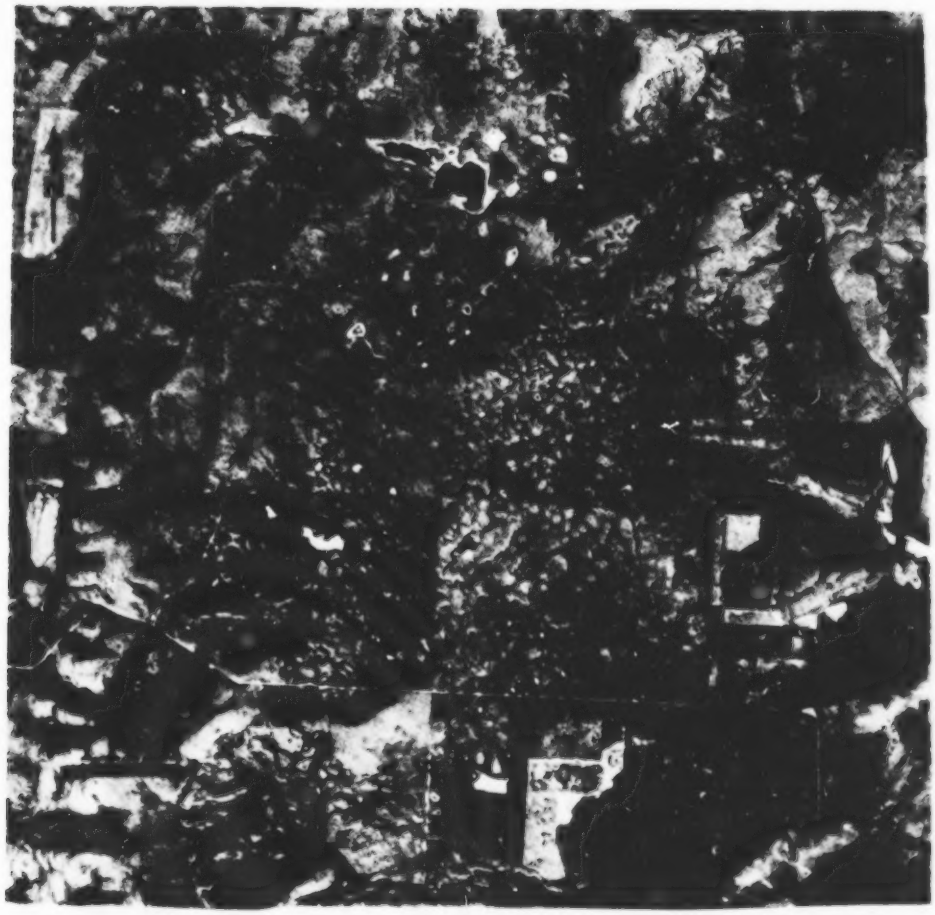

Figure 11. Hummocky moraine along the north end of the Porcupine Hills near Cross Creek (NE¼, tp. 16, rge. 2, W 5th mer.). NAPL A18306-109

Figure 12. Coarse bouldery glacial rubble south of Lawson Lake in the upper Kananaskis River drainage basin. Individual blocks reach 5 m in longest dimension. This deposit probably originated as a large rockfall onto glacial ice which was let down during deglaciation. ISPG 959-8

commonly are isolated mounds (rather than dispersed into sheets which is typical of rockslide deposits) demands secondary transport and concentration. The most reasonable explanation appears to be a combination of a rockslide origin and glacial transport and deposition; a rockslide cascaded onto glacial ice, was transported to the terminus, and there was let down as a pile during ablation as proposed by Rutter (1972) for a similar deposit at Moraine Lake. This explanation is supported by the frequently concentric forms of these deposits when viewed from the air (such patterns are commonly seen in morainal material deposited at former glacial termini).

The rockfall-like nature of these deposits may cause them to be initially confused with actual rockfall deposits. However, a distinction between the two is important. The glacial rubble piles have been transported to their locations by ice and do not necessarily indicate slope instability in adjacent valley walls. They probably do indicate past and potentially continuing instability somewhere upvalley. Rockslide deposits, however, indicate past and potentially continuing instability in valley walls adjacent to their location.

Glacial rubble piles may be distinguished from rockslide deposits on the following criteria:

1. The rubble pile is usually an isolated ridge or series of concentric ridges which appears to have been dropped vertically into place rather than by sliding or flowing into place from adjacent uplands.
2. Rubble piles usually have a concentric shape or form a series of concentric ridges which are concave in an upvalley direction.
3. One or more steep faces are typically present along the upvalley sides of rubble piles.
4. Isolated large blocks of the same lithology as the rubble pile are usually scattered across the adjacent land surface in the general vicinity of the main rubble pile or piles.

Land use and vegetation. Some vegetation occurs on these deposits where silts have filled depressions on the surface of rubble. Subalpine fir, subalpine larch, and Engelmann spruce are dominant tree species. The large size of bedrock blocks within these deposits would make any attempt to alter the rubble piles similar to problems of altering the bedrock itself. At the same time, the bouldery rubble is granular and should not be expected to have the same bearing characteristics as the undisturbed bedrock.

Bouldery till and ridged morainal deposits (bMr, Mr, bcMr)

These deposits occur in the high mountain regions of the study area and are typically close to cirques. The bouldery nature of the till is primarily a result of the short distance of transport of eroded material to the site of till deposition. The ridged deposits in this group are lateral moraines. The blanketing deposits form intervening ground moraines. Bouldery ridged and blanketing morainal deposits are most common adjacent to present glaciers along the Continental Divide, especially in the area of the headwaters of Kananaskis River and the region to the south. Deposits in these areas are predominantly less than 200 years old and may still contain lenses of ice. Similar deposits originating from Pleistocene and early Holocene age advances, however, are found throughout the high mountain regions of the study area adjacent to cirques.

Modifying surficial processes. The bouldery nature of these deposits makes their erosion hazard low. Where they have been recently deposited, ridged moraines are often unstable and prone to slumping.

Vegetation and land use. These deposits lie at or above treeline so that species of large shrubs and trees are restricted to willows, subalpine larch, and subalpine fir. Alpine tundra usually predominates. Very recent deposits are usually devoid of vegetation except for lichens and the first colonizing alpine vascular plants such as **Dryas** and willow. Land use in these areas is limited to recreation and range for alpine animals.

Glaciolacustrine and lacustrine deposits

Extensive glacial lakes were ponded by ice retreating down the regional slope during the deglaciation phases of past glaciations in the easternmost Foothills and Prairies of the study area (Stalker, 1973, p. 45-47; Jackson, 1981). Glaciolacustrine deposits, each measuring many square kilometres, now mark the former basins of these lakes. In the Front Ranges and Foothills of study area, where ice retreated up valley, smaller areas of ponding were the rule. The only

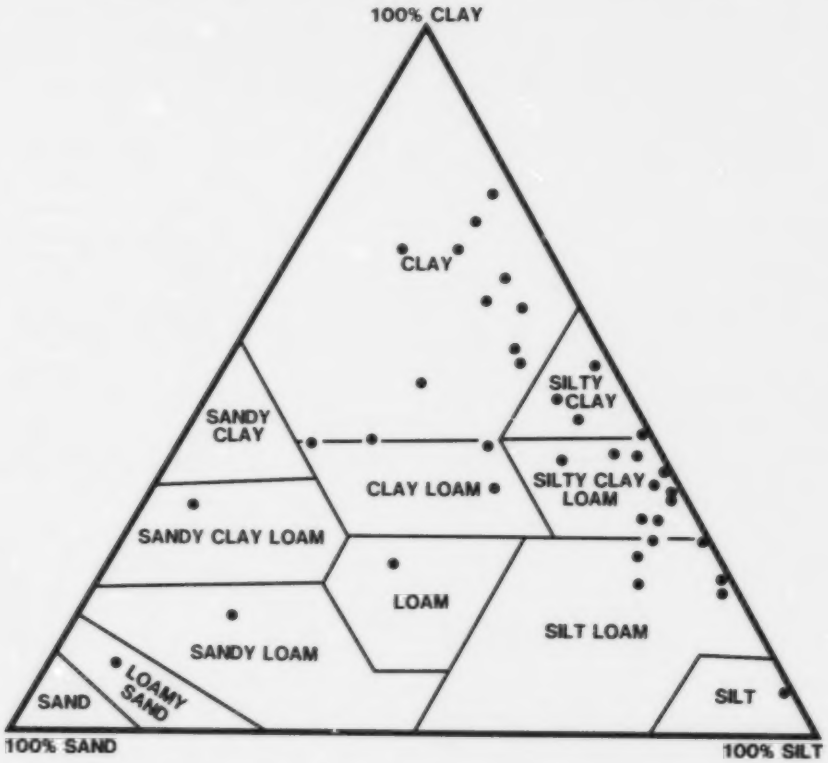

Figure 13. Textural classification of glaciolacustrine sediments of the study area based upon their contents of sand, silt, and clay.

indication of the existence of these small water bodies is the interstratification of glaciolacustrine deposits with outwash deposits as seen in natural exposures and exploratory borings.

Lacustrine deposits originate in lakes that are not ponded by glacial ice and are not fed by glacial meltwaters. Lacustrine deposits are often impossible to differentiate from glaciolacustrine deposits where sedimentation continued in local depressions on glacial lake floors following the draining of the parent glacial lake (e.g., St-Onge, 1972). Known lacustrine deposits were not sampled during the course of this study. Where they have been encountered in borings such as the north dam site of the Chain Lakes Reservoir, they are typically heavy clays to silty clays (Prairie Farm Rehabilitation Administration, 1967) similar to surrounding glaciolacustrine sediments.

Texture

Weight percentages of the sand, silt, and clay contents of the glaciolacustrine deposits almost exclusively fall within the fine sand to clay range. Textural data for the ≤ 2 mm fraction are presented in Figure 13. The majority of the samples have clay and silt contents in excess of 50% of the sample.

Stratification and colour

Glaciolacustrine deposits are commonly well stratified although the stratification is not usually apparent in roadcuts and some natural exposures. Man-made homogenization and surficial flow usually obscure stratification in such exposures. Where they are slightly pebbly, homogenized exposures can be mistaken for till. Bedding thickness is

Figure 14. Finely laminated glaciolacustrine sediments (A), overlying glacial till (C). The two units are separated by a suspected buried soil (B). ISPG 1146-3

Table 8. Survey of engineering properties of glaciolacustrine and lacustrine deposits from pre-existing exploratory foundation borings[1]

A. Easternmost Foothills and Prairies, CL and ML to CH and MH soils

	South Calgary Area[2,3]					Highway 22 between Millarville and Priddis Curve[4]					Quirk Creek Gas Plant[5]					Chain Lakes Reservoir[6] North Dam					Chain Lakes Reservoir[6] South Dam				
	$\bar{X}$	s	n	max.	min.	$\bar{X}$	s	n	max.	min.	$\bar{X}$	s	n	max.	min.	$\bar{X}$	s	n	max.	min.	$\bar{X}$	s	n	max.	min.
Penetration resistance, by standard penetration test[7] (blows per foot, 30.5 cm)	21	11.2	7	34	10	-	-	-	-	-	21	5.9	21	32	12	-	-	-	-	-	-	-	-	-	-
Unconfined compressive strength (kPa)	-	-	-	-	-	-	-	-	-	-	193	59	6	310	152	-	-	2	172	103	-	-	-	-	-
In situ moisture content (% dry weight)	15	3.4	12	20	10	27	3.2	30	36	20	28[8]	3.5	64[8]	35[8]	21	24	1.9	28	26	20	26	5.6	64	37	14
Atterberg limits (% dry weight)																									
Liquid limit	32	7.0	4	40	23	-	-	-	-	-	-	-	1	82	-	66	10.3	5	79	51	64	17.8	28	95	33
Plastic limit	19	3.9	4	24	15	-	-	-	-	-	-	-	1	29	-	21	4.6	5	27	17	22	3.1	28	28	15
Plasticity index	14	3.7	4	15	8	31	6.4	30	42	20	-	-	1	53	-	45	8.3	5	55	33	42	16.0	28	74	25
Wet density (kg/m^3)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1955	22.4	11	2003	1923	-	-	-	-	-
Standard Proctor maximum dry density (kg/m^3)	-	-	-	-	-	1602	85	23	1715	1458	-	-	-	-	-	-	-	-	-	-	1458	-	3	1635	1346
Optimum moisture content (% dry weight)	-	-	-	-	-	22	3.2	30	30	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

B. Kananaskis valley, Front Ranges, ML and CL soils

	$\bar{X}$	s	n	max.	min.
In situ moisture content (% dry weight)	19	3.4	9	24	15
Plasticity index (% dry weight)	9	2.8	9	12	6
Standard Proctor maximum dry density (kg/m^3)	117	6.2	9	130	110
Optimum moisture content (% dry weight)	13	3.0	9	15	10

$\bar{X}$ = arithmetic mean; s = standard deviation; n = number of samples; max. = maximum value; min. = minimum value

1 Glaciolacustrine deposits may be directly at surface or beneath loess or fluvial deposits; values not available are left blank in the table.

2 South of 51°N; sampling grid: one sample for about every 0.9 km^2 or where available in areas of sparse data. Data courtesy of the City of Calgary.

3 Source for South Calgary data: borings for Glenmore Village and Pentecostal Tabernacle; courtesy of R.M. Hardy and Associates, Calgary.

4 Data courtesy Alberta Transport,

5 Data courtesy Imperial Oil Ltd.,

6 Data courtesy Prairie Farm Rehabilitation Administration,

7 Test consists of driving a standard sampling spoon into the soil by dropping a 140 lb. (63.6 kg) weight from a height of 30 inches (76.2 cm). Data courtesy of the city of Calgary.

8 Values estimated from points plotted on borehole logs.

primarily a function of the texture of the deposit. Where glaciolacustrine sediments are sandy and silty, individual bed thicknesses usually range from a few tens of centimetres to as much as a metre.

Clayey glaciolacustrine deposits are commonly laminated with laminae ranging from about 1 to 5 cm in thickness. Laminae commonly alternate rhythmically between silty clay and heavy clay. Figure 14 shows laminated clayey glaciolacustrine sediments from the east side of Bow River valley south of Calgary.

The colour (in a dry state) of the glaciolacustrine sediments is a function of their texture. Silty and sandy deposits are usually light grey (10YR 7/1 to 10YR 7/2) ranging to white (10YR 8/1) and pale brown (10YR 6/3). Clayey sediments typically have a more yellowish hue with colours in the greyish brown, light brownish grey, and light grey range (2.5Y 5/2 to 2.5Y 7/2).

Atterberg limits

Atterberg limits were determined for some glaciolacustrine sediments. Liquid limit and plasticity index values from these samples are shown in Figure 15. Glaciolacustrine sediments from the easternmost Foothills and Prairies are generally of intermediate to high plasticity. This range of plasticities places the glaciolacustrine deposits of the eastern Foothills in the MI and MH and CH categories of the Unified Soil Classification scheme. The higher plasticity of glaciolacustrine sediments in the easternmost Foothills and Prairies as compared to the tills of the same area is due to the greater amounts of clay size particles in the glaciolacustrine sediments. This is corroborated by the nearly identical range of clay activities of both tills and glaciolacustrine sediments (Fig. 8). These values were found to be statistically indistinguishable. This is not surprising because the clays of both the tills and the glaciolacustrine deposits have the same dominant provenance – the bentonite-rich shales of the Upper Cretaceous and Paleocene bedrock of the Prairies and easternmost Foothills (Kodama and Brydon, 1966).

Atterberg limits from pre-existing engineering investigations in the study area are summarized on Table 8. Values are available for only four areas within the easternmost Foothills – the South Calgary area, Highway 22 between Millarville and Priddis Curve on the Priddis Bragg Creek Road, the Quirk Creek Gas Plant south of Priddis, and the north and south dam sites of the Chain Lakes Reservoir. Data values were selected from samples taken from borings at 300 m intervals along the highway route, which lies almost entirely within glaciolacustrine sediments. The Atterberg limit values in Table 8 fall within the general range of values as those determined on samples from the easternmost Foothills and Prairies during this study (Fig. 15).

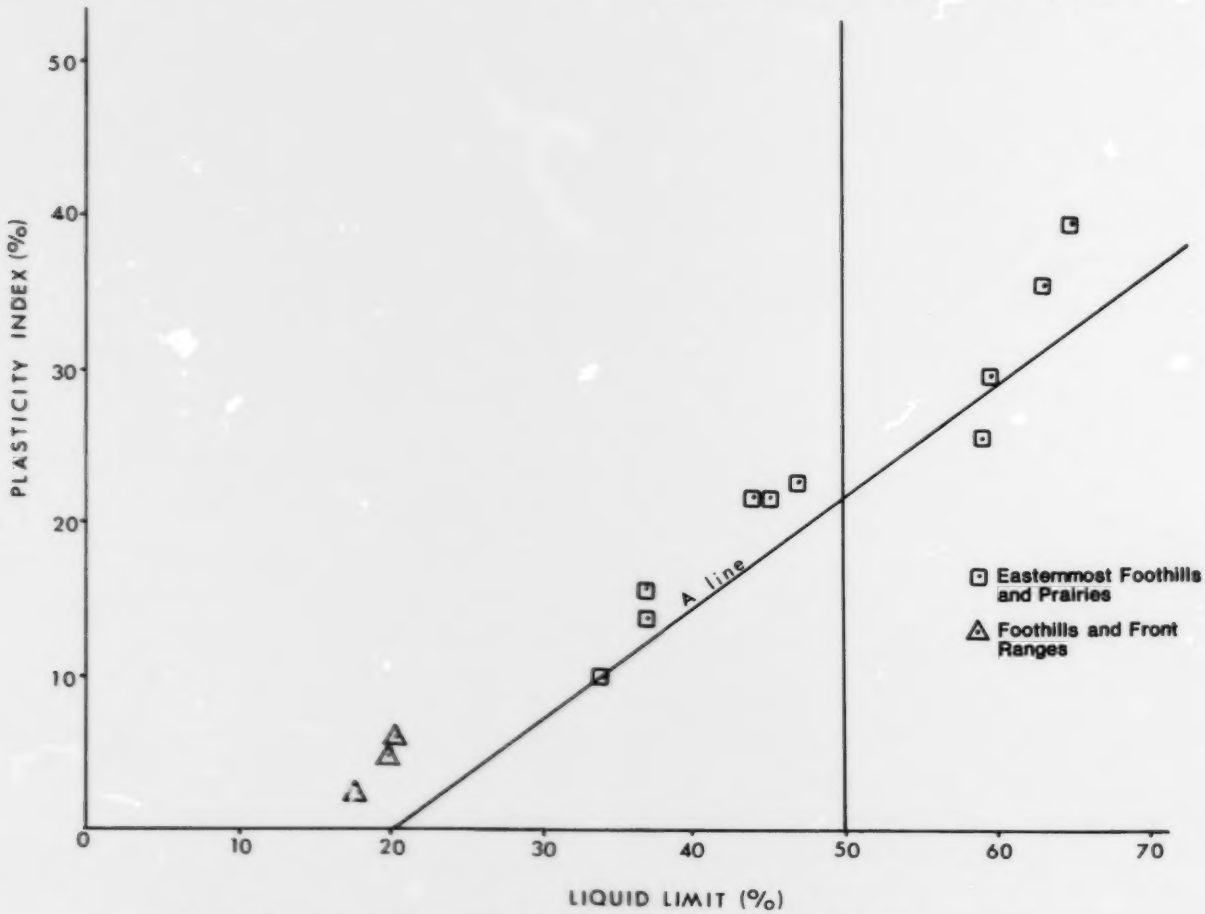

Figure 15. Plasticity index vs. liquid limit for samples of glaciolacustrine sediments from the study area.

Glaciolacustrine sediments from the Foothills and Front Ranges are of low plasticity – placing them in the CL and ML classifications of the Unified Soils Classification scheme (Table 8 and Fig. 8). This probably reflects both the low expansiveness of Foothills and Front Ranges clays, significant contents of nonclay minerals in the clay size fraction, and the sandier nature of the deposits.

Atterberg limits for lacustrine sediments are available only for the north dam site of the Chain Lakes Reservoir (Table 8). At this location, lacustrine sediments were deposited in a lake which occupied a meltwater channel floored by outwash. The Mazama ash lies about 3 m below the surface, identifying the overlying clays as being less than 6700 years in age and definitely nonglacial. These intermediate to high values are similar to those of the adjacent glaciolacustrine deposits. This is reasonable because the surrounding glaciolacustrine deposits and tills probably acted as the source of these lacustrine sediments.

Expansiveness

Figure 8 shows clay activity values (plasticity index versus clay content) for glaciolacustrine and till samples analyzed for this study. Glaciolacustrine sediments from the easternmost Foothills and Prairies typically fall in the range of high to very high swell potential according to the empirical classification method of Williams (1957). Vertical swelling pressures of 144 kPa and 241 kPa were determined for two glaciolacustrine samples collected during the foundation investigation for Quirk Creek Gas Plant (Imperial Oil Ltd., personal communication, 1976). These swelling pressures are significant and substantiates the categorization of the glaciolacustrine sediments in the easternmost Foothills and Prairies as having high to very high expansiveness (Fig. 8). Although no widespread conclusions can be drawn from only two values obtained from a single site, a potential differential heave hazard exists for structures built upon these deposits if these values prove to be representative.

Potential expansion problems may not be as serious for lacustrine sediments due to their usually higher in situ moisture contents.

Moisture content

In situ moisture contents from pre-existing borings are tabulated in Table 8. All samples used in the computation were taken from below the zone of seasonal moisture fluctuation. In situ moisture contents of glaciolacustrine deposits are typically at or above their plastic limit (except for the south Calgary area) with respect to the Atterberg limits shown in Table 8. Closer to the surface, seasonal fluctuation of moisture content causes the plastic limit to be greatly exceeded. Flowage and rapid creep of glaciolacustrine deposits in roadcuts through these deposits usually allows identification of clayey glaciolacustrine sediments from a distance (Fig. 16).

Figure 16. Tilted barbed wire fence on roadcut through glaciolacustrine sediments. Such evidence of relatively rapid creep allows the identification of these sediments from a distance.

Values from the north dam site of the Chain Lakes Reservoir were obtained from clayey glaciolacustrine sediments below the surface till. The north dam site is near the terminus of ice advance from the north during the last glaciation. At this point, the ice overrode glaciolacustrine sediments from a previous advance. The weight of the ice may have overconsolidated the underlying clays. This could account for the slightly lower mean moisture content relative to sediments from the same glacial lake at the surface at the south dam site.

Lacustrine sediments from the north dam site have in situ moisture contents well above the plastic limit, indicating that these deposits are relatively plastic in situ. The higher moisture content is probably related to the poor drainage conditions of the site. Lacustrine sediments (and some glaciolacustrine deposits) usually occupy similar enclosed or semi-enclosed depressions with poor drainage and water table close to the surface. Such deposits generally flow under light loads, and frequently have insufficient strength to support automobile traffic.

Unconfined compressive strength and penetration resistance

Unconfined compressive strength values for glaciolacustrine deposits exposed at the surface are available for the clayey glaciolacustrine sediments at the Quirk Creek Gas Plant (A of Table 8). As with till, variations in unconfined compressive strength probably originate from sample remolding during sampling operations, textural variations, and variations in stress history, for example desiccation.

Standard penetrometer values are available for the Quirk Creek site and the south Calgary area (Table 8). Unlike penetration values for till, which reflect stone content rather than strength, the penetration values of the comparatively stone-free glaciolacustrine clays should more closely reflect actual strength properties.

The mean values and ranges of values of penetration resistance are similar for both the Quirk Creek site and south Calgary area. The available data suggest this to be more than coincidence because the moisture contents of most of these deposits are typically near the plastic limit which would indicate a similar degree of stiffness for these deposits. Since samples from all of the other sites in Table 8 have moisture contents close to the plastic limit, the range in values of 10 to 32 blows/ft appear to be a typical range of values for these deposits.

Unconfined compressive strength values for lacustrine sediments are available only for the north dam site of the Chain Lakes Reservoir (Table 9). These values are lower than those for glaciolacustrine sediments nearby and elsewhere in the easternmost Foothills and Prairies.

Standard Proctor and in situ densities

In situ wet densities, Standard Proctor densities, and optimum moisture content are listed in Tables 8. In place wet density values are only available for the glaciolacustrine sediments below the surface till at the north dam site of the Chain Lakes Reservoir. Although no data from elsewhere in the study area are available for comparison, it would seem

Table 9. Survey of engineering properties of lacustrine deposits (CL and CH soils) from the north dam site, Chain Lakes Reservoir[1,2]

$\bar{X}$	s	n	max.	min.
Unconfined compressive strength (kPa)				
110	18.6	9	117	62
In situ moisture content (% dry weight)				
34	3.8	18	36	28
Atterberg limits (% dry weight) Liquid limit				
49	10.4	37	65	32
Plastic limit				
17	3.2	37	27	13
Plasticity index				
31	8.8	37	46	14
Wet density (kg/m^3)				
1746	46.5	8	1794	1667

[1] Data courtesy Prairie Farm Rehabilitation Administration
[2] Values estimated from points plotted on borehole logs

likely that the values from this site would be near the high end of wet densities for similar CH and CI soils due to the stress history of this deposit (ice overriding). In general it appears that in situ moisture content of the glaciolacustrine deposits of the study area are wet of optimum moisture content.

In the easternmost Foothills Standard Proctor values for glaciolacustrine deposits were only available for a 13 km stretch of Highway 22, the first several kilometres of the road between Priddis and Bragg Creek, and the south dam site of the Chain Lakes Reservoir. Values for Standard Proctor maximum dry density and optimum moisture content were taken from borehole data from approximately 300 m intervals along Highway 22.

Figure 17 shows the plasticity index plotted against the maximum dry density and attendant optimum moisture content from highway borehole data. The "r" values for the two plots are 0.61 and -0.64, respectively (significant at the 0.01 level). The lower smaller positive and negative correlation coefficients for these plots in comparison to the plots for tills probably reflects the greater variation in texture among glaciolacustrine deposits.

Topographic form mapped terrain units

The rolling glaciolacustrine plain (Lm) is the most common glaciolacustrine unit in the study area. It is a flat to gently undulating plain and marks the floor of a previously existing glacial lake. The thickness of glaciolacustrine sediments below the plain may range from several metres along the edge of the unit to several tens of metres in the centre of the plain or over pre-existing depressions. Glaciolacustrine plains grade laterally into glaciolacustrine blankets (Lb) on hills which protrude through glaciolacustrine plains. The best example of a glaciolacustrine plain in the study area is the plain south of the town of Black Diamond (Map 2-1984). Glaciolacustrine blankets (Lb) are generally thin enough (1-3 m) so that the topography of the underlying bedrock is generally expressed. Glaciolacustrine blankets grade into glaciolacustrine veneers (Lv) over bedrock highs. Examples of glaciolacustrine blankets can be seen in the area of MacMillan Creek and in the Foothills west of

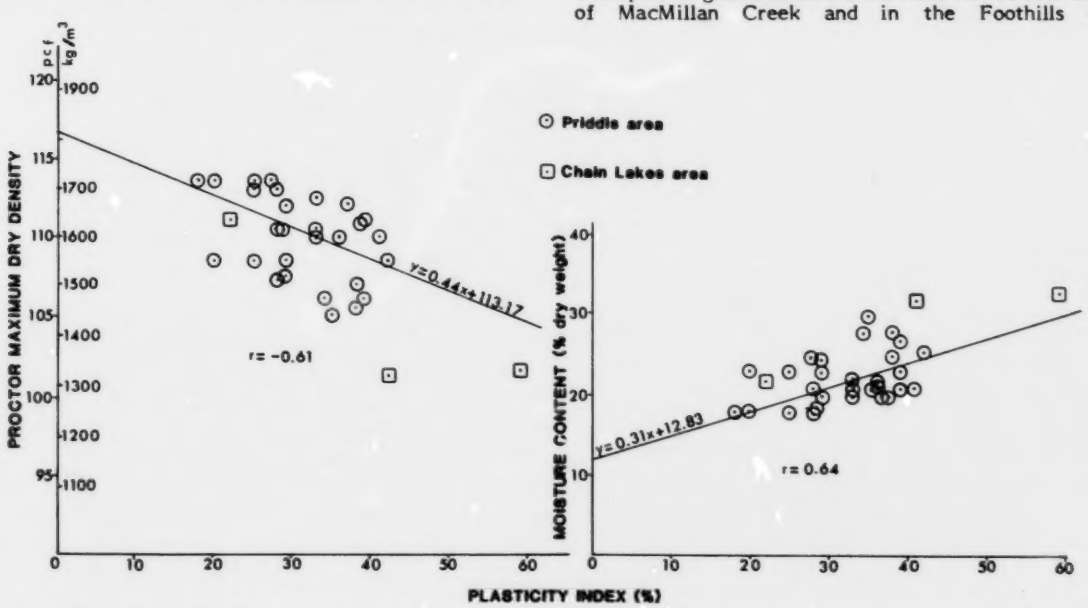

Figure 17. Standard Proctor maximum dry density and optimum moisture content vs. plasticity index for samples obtained from highway borings in the easternmost Foothills and Prairies of the study area. Lines are least squares regression lines defined by the accompanying equation. The correlation coefficient "r" accompanies each plot.

Turner Valley. The glaciolacustrine blanket deposits west of Turner Valley typically grade into glaciolacustrine veneer deposits along the perimeters of bedrock ridges.

The final glaciolacustrine terrain unit mapped in the study area is the hummocky glaciolacustrine deposit (Lh) which occurs along Pothole Creek about 10 km south of Priddis (Map 2-1984). These deposits appear to have been laid down in ice walled lakes. Relief of the hummocks ranges from 10 to 25 m. Exploratory highway borings in this area show these deposits to contain fine sand, silt, and clay, with minor interstratified gravels. The hummocky glaciolacustrine deposits grade laterally into hummocky moraine to the east and west. Due to the typically flat or gently rolling topography developed on most glaciofluvial deposits, erosion hazard is nil to low.

Vegetation and land use

Vegetation over most of the glaciolacustrine deposits in the study area is largely grass or forage crops. The major exceptions are the glaciolacustrine deposits west of Priddis and south of the town of Bragg Creek which are predominantly covered by lodgepole pine forest. The low relief of most glaciolacustrine deposits and their almost total lack of stones usually make them ideal for cultivation. Due to their clayey textures, however, they may be difficult to work in wet years. Hummocky glaciolacustrine deposits are used only for pasture.

The high clay content and low permeability of glaciolacustrine deposits makes them suitable sites for solid or liquid waste storage.

Glaciofluvial deposits

Glaciofluvial deposits result from deposition of sediment by flowing water away from, adjacent to, over, or under glacial ice. Glaciofluvial deposits are distinguished from till by their stratification and better sorting and from glaciolacustrine deposits by the predominance of coarse sand and gravel size clasts and sedimentary structures indicative of deposition under strong currents, for example, cross-stratification and imbrication of gravel size clasts. Two divisions can be made among glaciofluvial deposits on the basis of surficial form; ridged and hummocky glaciofluvial deposits (Gr, Gh) and planar glaciofluvial deposits (Gp). This two-fold division has more significance than merely separating hilly deposits from flat ones. The morphology of these deposits reflects their mode of deposition which, in turn, bears upon the lateral continuity, thickness, and texture of the deposits comprising them.

Ridged and hummocky glaciofluvial deposits are subdivided, for the purposes of this report, into kames and eskers. Kames, are defined by Flint (1970, p. 210) as "... a mound-like hill of ice-contact stratified drift, of any size". Kames are thought to form as fluvial deposits laid down on, abutting, beneath, or in crevasses of stagnant ice. Once the stagnant ice has melted, a small hill of glaciofluvial deposits is left. The stratified sediments composing the kame are commonly highly deformed, contorted, or faulted through slumping and differential settlement as the ice adjacent to kame ablates. Kame deposits in the easternmost Foothills of the study area are found either scattered within areas of hummocky moraine or as isolated deposits. Those found in hummocky moraine are often difficult to distinguish from the surrounding morainal deposits without drilling or trenching.

Isolated kames are more readily recognized. Figure 10 shows a kame located approximately 15 km east of Longview. Such deposits usually rise well above the surrounding ground moraine or can be seen forming a terrace-like surface along the contours of hillsides, marking the height of adjacent ice at the time of their deposition. Eskers are sinuous, continuous ridges or discontinuous ridge segments which were deposited by streams flowing in tunnels beneath stagnant ice. They are confined to areas of extensive kame deposits such as the area near the confluence of Evans-Thomas Creek and Kananaskis River in Kananaskis Valley. They are too small to delineate on Map 2-1984 and have been included with kame deposits.

The texture of kame deposits and their suitability for various uses depend on the sorting of the sediments, the manner in which they were deposited, and the provenance of the sediments. The sorting of kame deposits is usually poor with massive beds of poorly sorted silty sandy gravels typically the case rather than the exception. The poor sorting of these deposits characterizes ice-contact glaciofluvial deposits (Church and Gilbert, 1975). This is especially characteristic of kame deposits in hummocky moraine areas where the sediments may have cascaded into place from the surface through moulins in the ice. Isolated kame deposits, such as the one shown in Figure 10, are typically better sorted with a smaller content of fines mixed in with sand and gravel. The better sorting is probably a function of less rapid sedimentation and possibly a greater distance of transport of the sediment and a slower rate of sedimentation (although this can only be speculated on as much of the drainage associated with kames appears to have been across ice). Bedding within these deposits is massive – commonly several metres or more of sandy gravel. Some sand deposits are locally present within these deposits. The final variable associated with kame deposits which determines their usefulness is the lithology of the constituent sand and gravel particles. Kame deposits in the Foothills are commonly rich in argillaceous rock types derived from the local bedrock. Reworking of morainal deposits by glacial meltwater and short distances of transport of the sediment are probably responsible for the presence of these rock types. High argillaceous rock contents may make kame deposits unsuitable for aggregate or strong fill material. Each kame deposit must be individually evaluated in this regard.

Ridged glaciofluvial deposits in the Front Ranges and Foothills are usually poorly sorted with variable amounts of shales and siltstones. They are more bouldery and generally coarser in texture than kame deposits in the easternmost Foothills. The coarse texture of these deposits reflects both the coarse texture of the morainal deposits in the Front Ranges from which most of the clasts were derived and the steeper gradients generally present in upland areas. Extensive kame complexes, rather than isolated kames, are typical in the Front Ranges and Foothills. This probably results from the confining effects of the valley walls which would channel outwash flow over areas of stagnant ice (Fulton, 1967). One of the most extensive areas of ridged glaciofluvial deposits is located near the confluence of Evan Thomas Creek with Kananaskis River. Excavations for the new Kananaskis Road have revealed this area of undulating topography with relief of 50 m or more in some locations to be underlain by poorly sorted silty gravel.

Planar and terrace-surfaced deposits or outwash and valley train deposits, as they are more commonly called, are formed chiefly of sand and gravel laid down by sediment-charged meltwaters flowing away from an ice margin on a valley floor. Outwash deposits are distinguished from nonglacial fluvial deposits by the following criteria:

1. The presence of the planar or terraced sand and gravel deposits in areas not associated with a stream of sufficient competence to have transported the deposits to their present location (Clague, 1975, p. 220-235). The delta-like outwash deposit along a small tributary to

Tongue Creek (sec. 9 and 10, tp. 19, rge. 2, W 5th mer.) just east of Hartel (Map 2-1984) is an example of such a deposit.

2. The presence of pits or kettles on the surface of a planar or terraced sand and gravel deposit. These features mark the former location of ice blocks which were washed downstream from a glacier, stranded, and buried (Fulton, 1967, p. 7). Pitted outwash deposits on Pekisko Creek 5 km upstream from the Longview/Chain Lakes Road (Fig. 18) probably display the best examples of such features in the study area.

3. An upstream source for planar or terraced sand and gravel deposits in ice disintegration or end moraine deposits. A good example of this relationship can be found at the confluence of Westrup and Langford creeks, in the southeastern corner of the study area (sec. 18 and 19, tp. 13, rge. 2, W 5th mer.). Outwash deposits in this area are graded to morainal deposits laid down by ice which spilled across gaps in the Livingstone Range. The outwash in turn is graded to a former glacial lake which occupied the Happy Valley area.

Modifying surficial processes

The typically coarse textures and attendant permeabilities of glaciofluvial deposits makes erosion hazard on these deposits of little consequence. Local slumping and gullying may occur on the margins of these deposits along stream-cut cliffs. In mountainous areas where glaciofluvial deposits abut against valley walls, they may be subject to encroachment and inundation by slope deposits.

Vegetation and land use

Vegetation on these deposits ranges from grasses in the eastern Foothills to heavy forest cover in the central Foothills and Front Ranges. Kame deposits are unsuitable for agriculture due to their irregular topography and stony texture. Where these deposits are grass covered, land use is usually restricted to grazing. Outwash deposits, though flat, are commonly too stony to cultivate and so are also grazed. In many areas of the eastern Foothills, however, outwash deposits are capped by a sufficient thickness of silty loess to permit cultivation of forage crops.

Glaciofluvial deposits are also used as borrow areas for fill material such as road subgrade (where contents of incompetent clasts are low enough). A few glaciofluvial deposits in the study area contain sand in sufficient quantities to supply local winter road sanding operations.

The permeable nature and extent of glaciofluvial deposits may make them locally important areas for groundwater and potential unconfined aquifers. Local aquicludes of till may be present within these deposits and may create local perched water tables or artesian conditions. Glaciofluvial deposits are extremely poor substrates for solid or liquid waste disposal or storage sites due to their high permeabilities.

Colluvial deposits

Colluvial deposits in the study area are the most diverse group of sediments included under one heading. As used in this report the term colluvium includes all unconsolidated surficial material produced by the physical

Figure 18. Pitted planar glaciofluvial deposits along Pekisko Creek (area of sec. 33, tp. 17, rge. 3, W 5th mer.). NAPL A18309-16

and chemical weathering of bedrock and transported into place primarily by gravitational agents. It ranges from coarse angular bouldery deposits of talus at the bases of mountain slopes to clay-rich colluvial mantles in the Foothills. Thickness, texture, strength, stratification, and related properties of colluvial deposits vary with parent material, the degree of balance between physical and chemical weathering, the rate and distance of transport of colluvial components from point of origin, the mode of transportation, and subsequent modification by other processes such as fluvial winnowing. The following discussion of colluvial sediments deals first with colluvial deposits having significant contents of fine materials (colluvial blankets and veneers); for a summary of the processes acting on these sediments, the reader is directed to Carson (1976). The second group of colluvial sediments lacks significant fines (coarse bouldary colluvial fans and aprons); the reader is directed to Chandler (1973) and Carson (1976) for discussion of the mechanics of these deposits. The last group of colluvial materials is modified by permafrost; relevant literature is cited in that section.

Colluvial blankets and veneers on s_2 slopes or on slopes of less than 5°

These are the most common colluvial deposits in the Foothills of the study area and are also locally common within the Front Ranges. They consist of blankets and veneers of weathered bedrock either reposing in place or transported to their present locations by the processes of creep. The texture, structure, and thickness of these colluvial deposits vary according to changes in parent material, slope, intensity of weathering, degree of homogenization with other colluvial deposits developed on different parent materials, and the length of time the colluvium has been forming.

Colluvial blankets and veneers on sites with slopes of less than about 5° (Cb, Cv) consist of gravel to boulder size blocks of weathered bedrock separated at some points by a matrix of varying proportions of sand, silt, and clay size particles. In lower areas of the Foothills and the Front Ranges, which are covered by heavy forest and have an appreciable season where temperatures are above freezing, weathering has often progressed to the point that much of the colluvial sediments has been partly disaggregated to their smaller particulate components (sand, silt, or clay size particles). Curves A through D in Figure 19 show plots of cumulative weight percentages of constituent particle sizes for samples of colluvium developed on shales of the Kootenay Group and Wapiabi Formation, respectively. The curves plot almost the entire samples for both rock types; less than 5 per cent by weight of the constituent particles of these deposits were larger than 8 mm. Both display a marked bimodal particle size distribution with one mode between 2 and 8 mm and another in the silt and clay range. This is

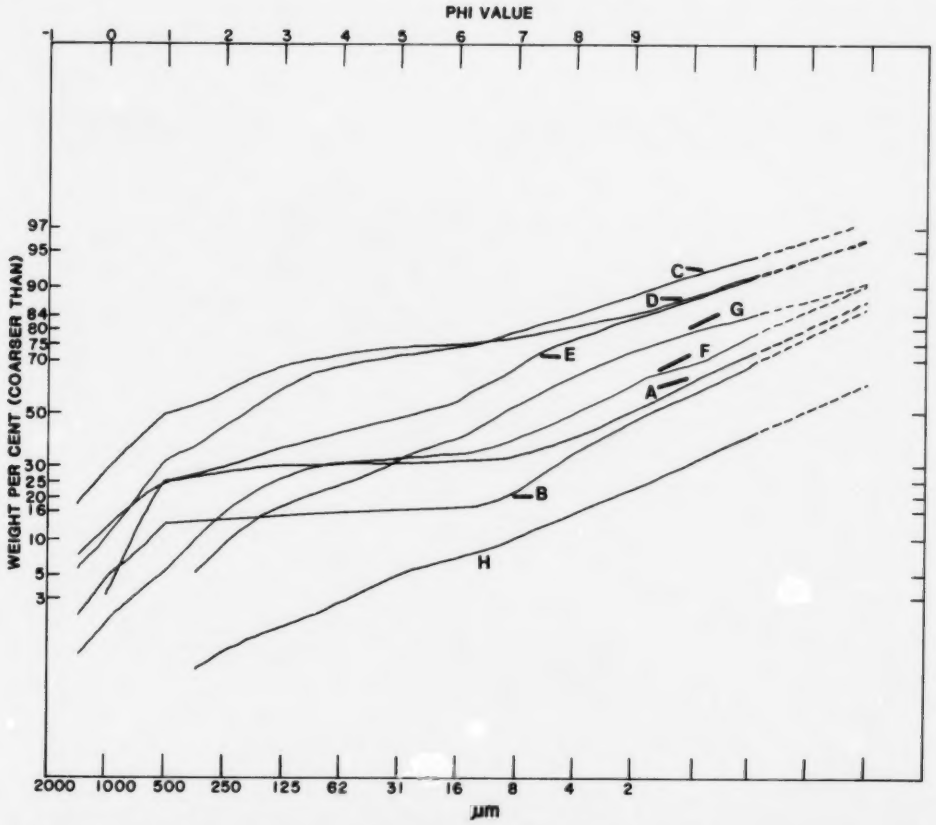

Figure 19. Cumulative weight percentages vs. grain size fractions less than 2000 µm for colluvial material sampled in the study area. Curves A to D represent samples of colluvium derived exclusively from the shales of the Kootenay Group and Wabiabi Formation. Curves E to H represent samples of colluvium derived from both shale and sandstone rocks. The bimodal curves associated with the shale-derived colluvium indicate direct breakdown from shale fragments to silt and clay size particles. The more unimodal curves for the sandstone and shale sizes are due to the mixing of the weathering products of the two rock types.

typical of colluvium developed from shales on nearly level locations. The shales of the study area typically weather to flaggy fragments of several millimetres to several centimetres in length. This shape is probably controlled by the flaggy structure and thin beds which are characteristic of most of the shales in the study area. These flaggy fragments appear to break down almost directly to silt and clay size particles as evidence by the almost complete lack of sand and coarse silt size particles. No sediment samples were collected from colluvium developed exclusively on sandstone, but quite different curves would be expected since the sand and silt size particles which compose sandstone are the smallest sizes the rock can be reduced to by disaggregation alone. Deeply weathered sandstones were observed in roadcuts at a number of locations. Exposures of some of these deeply weathered sandstone units reveal loose sand which could be mistaken for alluvial deposits if not for scattered core-stones of intact bedrock. Colluvium developed on carbonate rocks on level sites in the Foothills is stony and sandy. With higher elevation and sparser vegetation cover, disaggregation of rock composing colluvium becomes less complete, probably due to the slower rates of chemical attack of cementing materials in the cooler climatic conditions of upland rates. Colluvium on level or sloping alpine sites (above about 2300 m elevation) commonly consists of angular blocks of underlying parent bedrock in a matrix of sand and silt size grains of the same material; the designators b$\not$Cb, b$\not$Cv, bCb, and bCv are used to denote such areas, depending on the boulder content. The coarse rocky nature of colluvial deposits at higher elevations is primarily the result of the predominance of physical over chemical weathering processes.

Thicknesses of colluvial blankets and veneers on level and near level sites are difficult to measure due to lack of exposures and borings and the gradational contact with the underlying bedrock. In the eastern Foothills, disaggregation of sandstones to sand extends 3 m or more below the surface in some places. Colluvium developed on shales in the same area extends at least 2 m. Colluvial cover usually decreases in thickness with increasing elevation.

Atterberg limits

Colluvial blanket deposits both on level sites and on s_2 slopes are the only groups of colluvial deposits which have sufficient clay content to warrant determination of their Atterberg limits. Figure 20 is a plot of liquid limit versus plasticity index for colluvial blanket deposits from sloping and nearly level sites throughout the Foothills and Front Ranges. Almost all of the values are of low to medium plasticity. On this basis most colluvial blankets and veneers would be classed as GM and GI soils in the Unified Soil Classification scheme. Clay activities for the same samples (Fig. 21) are all less than 0.5 and, typically, have low swell potentials. No Atterberg limit data were collected for colluvial deposits in the easternmost Foothills and Prairies. Because of the large content of mixed layer expansive clays in the Paleocene and Upper Cretaceous shales in this area, however, colluvial deposits derived from them should have plasticities and clay activities similar to the tills and glaciolacustrine deposits of those areas.

Modifying surficial processes

Colluvial blankets and veneers on s_2 slopes are in continuous or periodic motion (albeit imperceptible) in a net downhill direction due to such processes as freezing and thawing, expansion and shrinking of clays with changes in water content, and burrowing (Hutchinson, 1968, p. 688-689). These processes are collectively referred to as creep. Rates of creep in colluvium have been found to be approximately proportional to the log sine of the slope angle for s_2 slopes investigated immediately north of the study area (Harris, 1971, 1973). Slope movements ranged between 40 mm on a 5° slope to 130 mm on a 34° slope over a

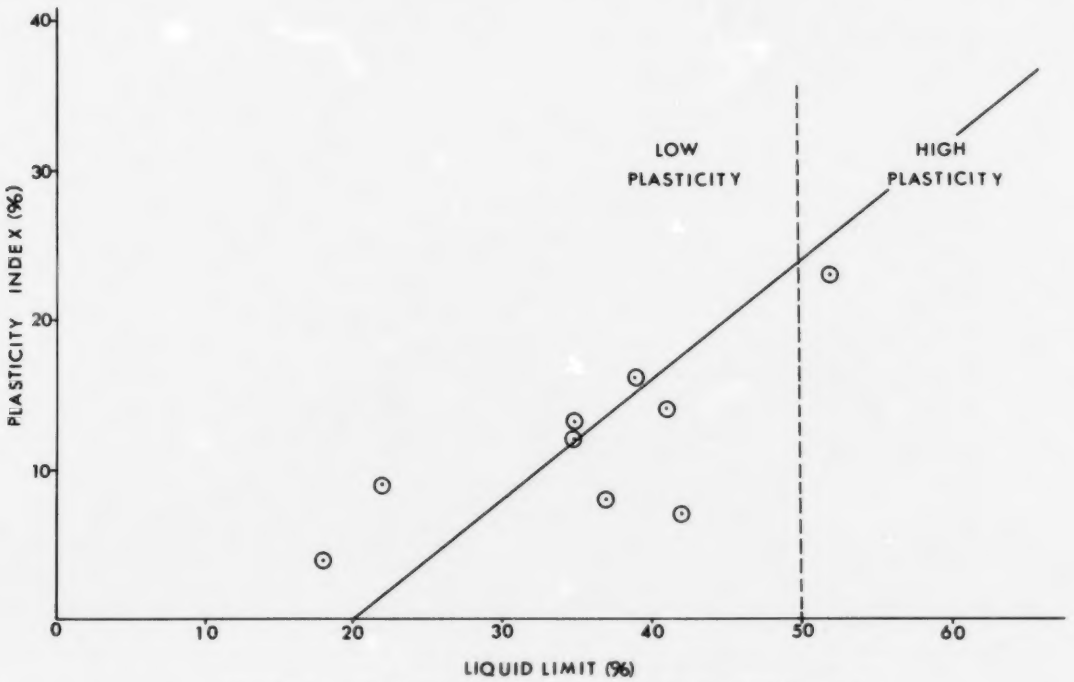

Figure 20. Plasticity index vs. liquid limit for colluvial samples.

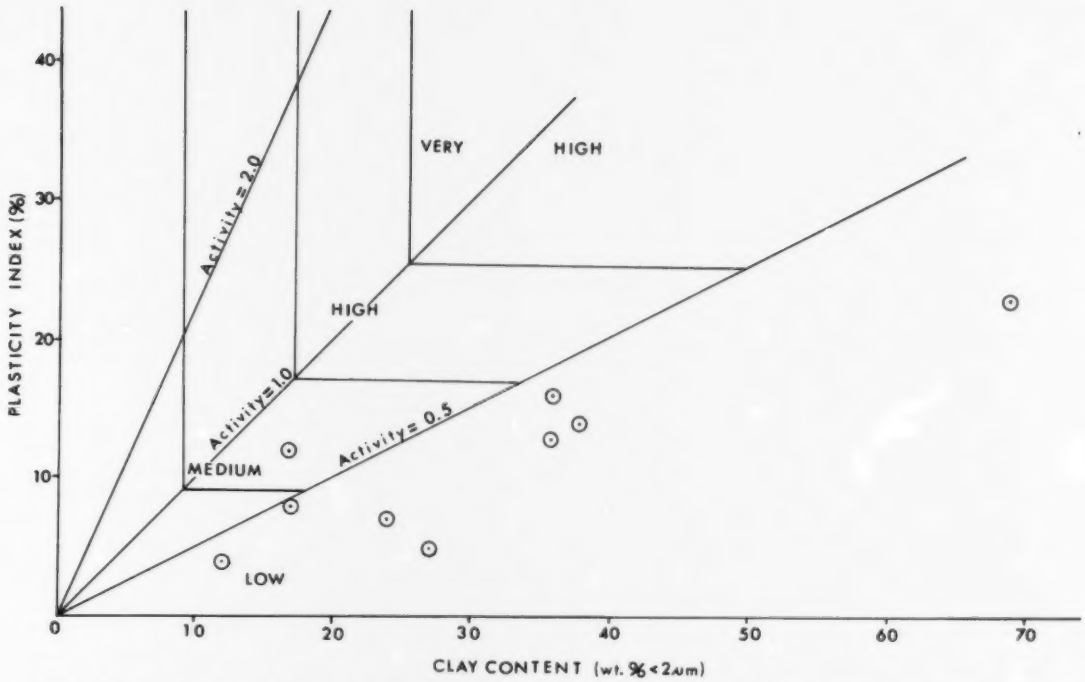

Figure 21. Clay activities of colluvial deposits sampled in the study area. All samples have low potential expansivity.

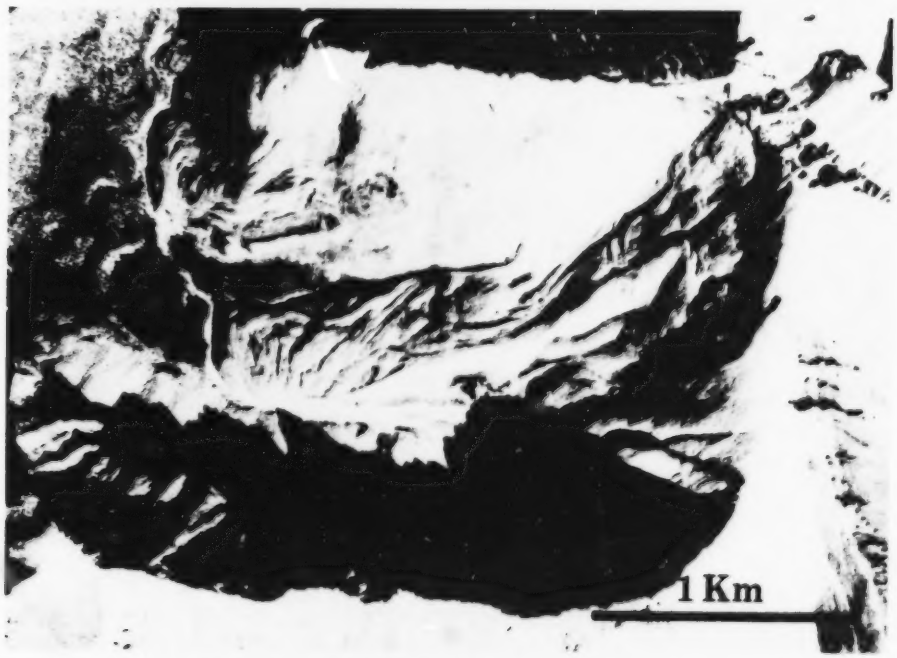

Figure 22. Two active rock glaciers on the southwest flank of Mount Bogart near the Spray Lakes Reservoir. NAPL A11102-22

six month period. Although these figures are the result of short term monitoring and their direct extrapolation to similar areas of the study area might be questionable, their general magnitudes are probably applicable and indicate creep to be a significant process of slope denudation. Furthermore, the proportionality of creep rate to log sine of slope has been demonstrated by Schumm (1967) for alpine areas in Colorado. Therefore, it probably has wide applicability in the Rockies. Creep homogenizes colluvium derived from the various rock types that may underlie a slope. Where sandstone, shale, and/or carbonate rocks underlie a single slope, the colluvium progressively takes on a till-like texture in a downslope direction. Figure 19, curves E to H, are samples taken from slopes underlain by both sandstone and shale and are comparable to similar curves for till in their proportions of sand, silt, and clay. The structure of these colluvial deposits are influenced also by the creep process. Clasts in colluvial deposits on s_2 slopes often show a subparallelism of their long axes in the direction of slope.

The thickness of colluvial deposits on slopes usually decreases with increasing slope inclination and varies according to the position on the slope. The contact with the underlying bedrock is generally abrupt or less gradational beneath colluvial deposits on s_2 slopes than on flat sites. Slope toes are typically areas of accumulation of creep-transformed colluvium and are generally much thicker than deposits farther upslope. Also, slope-toe deposits may contain considerable stratified material deposited by ephemeral streams draining adjacent slopes. Absolute values of colluvium thicknesses are as variable as slopes are numerous. Thicknesses may range from nil on steep slopes of 30° or more to several metres on gentle slopes. Thicknesses of slope-toe deposits may range from a few to ten or more metres. Colluvium on slopes may also contain variable amounts of glaciofluvial deposits and till; these deposits are mapped as colluvium where the distribution is so patchy that they cannot be discerned at the scale of mapping. Colluvium blanketing s_2 slopes becomes more bouldery and sandy with increasing elevation, due to increasing dominance of physical weathering processes over chemical weathering processes. Solifluction is the dominant process of creep in alpine colluvial s_2 slopes (Benedict, 1970). For example, lobate tongues of bouldery to silty carbonate colluvium can be seen overriding meadow soils on the hilly floors of cirques on the east side of the summit of Moose Mountain. The symbols $b\not{s}Cb_2$, bCb_2, $b\not{s}Cv_2$ and bCv_2 are assigned to these deposits depending on texture; thicknesses of 3 m or more have been recorded at some locations.

Man's activities are becoming increasingly more significant in initiating or accelerating processes which alter colluvial blankets and veneers or any other slope deposits in the study area. These activities include timber harvesting and cutting, roads for coal exploration, and of seismic lines. Numerous studies (e.g., Gray, 1972; Swanson, 1975) have linked logging with acceleration of creep, rising water tables, lowering of cohesion of the colluvial mantle with underlying bedrock, and other factors which generally reduce slope stability. Road construction on mid-slopes, which is usually practiced with logging and coal exploration, has been shown to be a major factor in accelerating fluvial erosion and reducing slope stability in colluvial deposits (Fredriksen, 1970). The degree to which these activities have affected slope processes in the study area has not yet been determined; however, judging by the studies cited above, the effects may be significant. Excavation and construction in colluvial blankets on s_2 slopes may prove to have troublesome results over long periods of time; creep of the colluvial blanket could deform a structure if it acted to impede movement.

Vegetation and land use

Colluvial blankets and veneers in the study area cover all s_2 slopes and slopes of less than 5° not covered by till or glaciolacustrine sediments. This includes most of the Foothills of this area. Thus, most of the merchantable timber grows on this substrate. Logging is the most widespread commercial activity carried out. These same forested lands provide a wide variety of forest-related recreational activities and comprise much of the watershed area for the streams which drain the area. Where they are grass-covered in the easternmost Foothills, colluvial soils are usually too stony for cultivation and are used for grazing. In alpine areas, they are typically covered by alpine tundra vegetation or grasses and locally support critical winter ranges for ungulates.

Colluvial blankets and veneers on s_1 slopes

Colluvial blankets and veneers on s_1 slopes (Cb_1, Cv_1) include bouldery to clayey colluvial deposits, similar in texture to those described on s_2 slopes, which are potentially or have been subject to erosion or burial by local periodic debris flows or avalanches of rock and snow from steep or unstable areas of bedrock upslope. These deposits are usually located above 1500 m in the Foothills and Front Ranges.

Textures of deposits on these slopes are typically bouldery upslope. In a downslope direction colluvial blankets and veneers grade into more gravelly and better sorted colluvial fans or aprons along the base of the slope. Debris flows or avalanches which descend these slopes usually follow well established paths or chutes. They terminate in a colluvial fan or apron built of avalanche, debris flow, and fluvial deposits. Areas between these chutes are commonly forest covered. Vegetation in avalanche chutes consists of grasses, shrubs, and young trees. The ages of the more brittle varieties of these trees, such as spruces and firs, give a minimum length of time since the last major avalanche or debris flow.

Colluvial blankets and veneers with appreciable fine grain fractions on slopes not presently cut by avalanche chutes are denoted Cb_1 and Cv_1; those crossed by avalanche chutes are designated Cb_1 [A or Cv_1 [A.

Vegetation and land use

Colluvial blankets and veneers on s_1 slopes are typically less than 1 m thick and commonly are bouldery in texture. As a result, trees in these areas have little or no commercial value. Those trees present in higher areas of slopes are often noneconomic species such as subalpine fir and alpine larch. Roads are usually difficult to construct and maintain across these steep slopes where stands with commercial value are present. The avalanche hazard and slope steepness usually restrict recreational activities to the summer months.

Coarse bouldery colluvial fan and apron deposits

Coarse bouldery colluvial fan (cbCf) and apron (cbCa) deposits include non-ice-cored bouldery deposits which form fans and aprons along the bases of s_1 slopes in the Foothills and Front Ranges. These deposits and the processes shaping them have been summarized by Luckman (1978). They are primarily deposited by gravitational processes such as free falling rock debris, sliding or skipping of rock, snow avalanches, and slush and debris flows. For the purposes of this report this group of deposits is divided into three subgroups: coarse bouldery colluvial aprons, avalanche-modified bouldery colluvial veneers and blankets, and colluvial fans.

Coarse bouldery colluvial aprons

Coarse bouldery colluvial aprons (cbCa) are debris piles formed at the bases of steep resistant bedrock slopes and are usually referred to as talus cones, fans, or slopes. These deposits are composed primarily of angular, boulder size fragments with long axis dimensions ranging up to 0.5 m or more. The unweathered coarse, angular, blocky nature of these deposits indicates that they are the direct products of loosening and detachment of bedrock fragments along cracks and joints by frost action. Where these deposits are located along the bases of near-vertical rock walls, they form uniform slopes or aprons and are probably the direct results of rocks falling from the adjacent walls. Where they are situated at the mouths of avalanche chutes, they form cone or fan-like deposits and receive much of their material from debris flows and snow avalanches. The slopes of these deposits are usually steep. Gardner (1969, 1970a, b, 1971a, b, 1973) studied three types of deposits in the Lake Louise area, about 40 km northwest of the study area. For twenty such slopes he found a mean slope angle of about 26° (Gardner, 1971a). This figure is probably applicable to the study area. Lengths of the slopes forming these deposits may be measured in the tens to hundreds of metres. The angular boulder-size fragments which compose the deposits are typically at or close to their angles of repose. Consequently, these deposits are only metastable and continuously shift through "subsidence, rolling, slides and true creep" (Gardner, 1969, p. 318).

The thickness of these deposits can only be estimated by projection of the contours of adjacent nondebris-covered valley walls beneath talus cones or slopes. Estimated thicknesses up to 10 m or more are common for these deposits.

Vegetation and land use. The unstable nature of these deposits, their lack of fines, and their periodic inundation by rockfalls and avalanches restrict vegetation to lichens, scattered stunted trees, and creeping vine-like shrubs. The deposits have little possible land use potential due to the hazardous processes which shape them, their steepness, difficulty of traverse, and lack of vegetation.

Avalanche-modified bouldery colluvial blankets and veneers on s_1 slopes

These bCb_1 [A, bCv_1 [A deposits consist of thin blankets and veeners (usually less than 1 m thick) of unweathered angular bouldery to gravel size bedrock fragments mantling steep slopes above timberline. Slopes upon which these deposits are found are commonly cut by avalanche chutes or otherwise bear evidence of avalanche activity. The angular character of these deposits is the result of the breakdown of the underlying bedrock by frost action along joints, cracks, and bedding planes. The shape of constituent particles is usually a function of lithology. Shale fragments generally are thin and flaggy whereas carbonate and sandstone fragments are irregular and blocky. Steepness of the slopes upon which these deposits rest are commonly close to or above the angles of repose of the colluvial mantle; consequently, these deposits are metastable. Creep and small slides are probably the most significant transportational agents. Strong gusts of wind alone have been observed to set individual clasts into sliding motion on some slopes.

Vegetation and land use. The instability of these slopes, plus their high elevation, usually confines vegetation to lichens and scattered alpine vascular plants. Recreational pursuits and habitat for a few alpine animals are the only land uses in these areas.

Colluvial fans

These deposits (Cf [A, Cf [W) are gradational between alluvial fans and colluvial aprons. They are situated at the bases of avalanche chutes and receive both avalanche and debris flow material as well as fluvial deposits carried by streams occupying the avalanche chutes. Sections through these deposits reveal massive bouldery diamicton beds interstratified with fluvially deposited silty sandy gravels. Colluvial fans are designated as being modified by either fluvial or avalanche activity; one activity modifier or the other is indicated on Map 2-1984 depending upon which process appears to dominate the deposit, based on airphoto interpretation of the surface morphology. Colluvial fans usually have lengths from apex to toe of several hundred metres and estimated thickness range up to several tens of metres. Good examples of colluvial fans occur along the northeast side of Bryant Creek valley in the northwest corner of the study area.

Vegetation and land use. Vegetation on these deposits usually consists of mixed conifers and deciduous trees. The density of the forest is dependent on the activity of the fan (i.e., the frequency of avalanche invasion and shifting of the channels). Active fans commonly are only sparsely vegetated. The hazards posed by flooding and avalanches on these deposits confine land use to summer recreational activities and wildlife habitat.

Rock glacier

Rock glacier (cbCa [I) is a comprehensive term for a family of landforms which externally are glacier-like tongues of bouldery debris extending from cirques or steep valley sides. Summaries of the morphology of rock glaciers are given by Johnson (1978) and White (1981, p. 132-131). Rock glaciers may vary in internal structure from glacial ice completely covered by bouldery debris to masses of bouldery debris cemented by ice. The former class have been called debris-covered glaciers (Vernon and Hughes, 1966, p. 17-22), ice-cored rock glaciers (Potter, 1972; White, 1976; Jackson and MacDonald, 1980), and moraine rock glaciers (Johnson, 1978). The latter class includes the avalanche rock glaciers and talus-derived rock glaciers of Johnson (1978). The bouldery surfaces of rock glaciers are commonly marked by longitudinal and concentric transverse ridges (Fig. 22) and, in places, by collapse pits.

Rock glaciers in the study area are confined to areas above timberline and below vertical cliffs composed of thick bedded carbonates and quartzites.

Modifying surficial processes

Most of the rock glaciers in the study area have steep scarp-like snouts which characterize active downslope movement (Wahrhaftig and Cox, 1959). Rates of advance of rock glaciers in this area of the Rockies range from 0.3 to 0.6 m/a over a seventy year period (Osborn, 1975). Jackson and MacDonald (1980) have recorded downslope displacements of segments of the Tungsten ice-cored rock glacier in the Selwyn Mountains of the Northwest Territories of up to 51 m and snout advance of up to 7.1 m over the period 1963-1980, or rates of displacement of 3 m/a and 0.4 m/a, respectively. All rock glacier deposits in the study area should be assumed to be in downhill motion unless proved otherwise. Collapse of parts of both active and dormant rock glaciers may also occur due to the melting of underlying ice.

Vegetation and land use

Vegetation is restricted to lichens. Recreational activity is the only land use on rock glaciers.

Colluvium resulting from periglacial processes

Permafrost is continuous above the timberline over most of the study area (Harris and Brown, 1982). Although seasonal frost activity acts to modify the near surface deposits throughout the Kananaskis Lakes region, periglacial landforms and deposits (i.e., Washburn, 1973), are widespread over areas above timberline having the following characteristics: 1) above about 2260 m in elevation, 2) underlain by carbonate or quartzite bedrock, and 3) a gentle enough site so that bedrock fragments do not roll away after being loosened by frost action.

Coarse, blocky colluvial mantles formed by past or present periglacial processes in various stages of accumulation may be seen on the summits of Moose Mountain, Forget-me-not Mountain, Plateau Mountain, Pasque Mountain, and numerous similar locations in the Front Ranges. The colluvial mantle in these areas is usually marked by patterned ground (Washburn, 1956) – typically sorted stone polygons on flat lying sites and furrow-like rock stripes on sloping sites. Stony polygons range from less than 1 m to several metres in diameter. The centres are usually sandy and gravelly with the margins composed of coarser, angular rock debris. Rock stripes consist of small parallel ridges, 30 cm or less in height, and composed of upturned angular gravel and boulder size stones. Where finer grained sediments underlie slopes in alpine areas, lobate solifluction landforms such as stone-banked lobes and terraces (Sharp, 1942) are common features. The most extensively developed area of patterned ground and solifluction features in the study area occurs on and around Plateau Mountain. On the mountain summit, boulders as large as 50 cm are common in the perimeters of rock polygons (Fig. 23). Lobate solifluction features are common on surrounding slopes. The Plateau Mountain alpine permafrost debris is the only patterned ground in the study area to be conclusively linked to currently active permafrost. Drill hole data have shown below freezing temperatures to persist to depths exceeding 30 m below the mountain's summit (Harris, 1979). The depth of frost shattered bedrock, however, extends only about 3 m below the surface. Areas of permafrost-modified colluvium or suspected permafrost-modified colluvium are designated cbCb [I.

Figure 23. Patterned ground on top of Plateau Mountain. Rod lying in centre of polygon is 1.5 m in length. ISPG 959-9

Modifying surficial processes

Areas of permafrost-modified colluvium may undergo significant seasonal heaving and creep due to seasonal freezing and thawing near the surface. These movements could potentially have deleterious effects on structures. Further studies would be necessary to evaluate this hazard on a site to site basis.

Vegetation and land use

Vegetation is restricted to lichens, low and stunted forest shrubs. Land use is typically restricted to recreation and fire lookout sites. A major exception is the top of Plateau Mountain on which several gas wells of the Savanna Creek gas field have been drilled.

Landslide deposits

Landslide deposits (LS) consist of large masses of bedrock which have become detached from the surrounding bedrock and have slid, rotated, or flowed to their present position. Mappable landslide deposits in the Foothills are primarily rotational slumps which grade into earth flows at their toes. Two large slumps several kilometres west of Volcano Ridge in the headwaters of Three Point Creek drainage basin and several kilometres downstream from the Elbow River-Little Elbow River confluence (Map 2-1984) described by Cruden (1976) are good examples of this type of failure. Landslide deposits in the Front Ranges are typically rockfall deposits too small to be mappable at 1:125 000 scale. One major exception is the Mount Indefatigable landslide at the west end of Upper Kananaskis Lake. The landslide is the culmination of at least two bedding-plane failures along the southwest side of Mount Indefatigable (Map 2-1984). The landslide is strongly undulating and is composed of coarse bouldery limestone rubble. The great length of the lobes (up to 2 km), their rubbly textures, and undulating surface indicate a grain flow mode of emplacement for the slide analogous to the sturtzstrom of Hsu (1975). The older lobe, which may be up to several thousand years old, has a poor soil developed on it and supports dense forest growth. The most recent lobe is devoid of vegetation with the exception of the lichen **Xanthoria elegans**. Growth curves for this lichen (Osborn and Taylor, 1975) indicate that the age of this lobe is greater than 200 years. The multiple occurrence of massive bedrock failure in this area, plus the relative youth of the youngest landslide, points towards the possibility of future slope failures in this area.

Eolian deposits

Eolian deposits are sandy and silty sediments eroded and transported exclusively by the wind. Eolian deposits form widespread discontinuous veneers over much of the Prairies and valley floors in the Foothills and Front Ranges. These deposits were not mapped due to their discontinuous character and their close conformity to underlying topography. These attributes make closely spaced augering necessary in order to accurately depict the lateral extent of eolian deposits. At the few points where eolian deposits are thick enough and exposures are sufficient so that their lateral extents may be defined, their areas are too small to be represented at the present scale of mapping. Eolian veneers or blankets should be expected throughout the study area on all horizontal or gently dipping terrain and especially in depressed areas of hummocky terrain.

Texture and modifying processes

Eolian deposits, which are dominantly loess, in the study area range from silt to fine silty sand in texture (ML soils) and are typically massively bedded without any

visible sedimentary structure. They are typically 1 m or less in thickness although greater thicknesses are locally observed. Loess can be distinguished from similar deposits, i.e. lacustrine, in that it mantles topography upon which soils have developed and occasionally has buried human artifacts. Loess deposits commonly contain nonaquatic animal remains. Dune sand deposits are rare.

Because loess deposits are typically found mantling level or gently sloping sites, erosion hazard on them is generally low. Gullying locally occurs in eolian deposits along cliffs. Because of the thinness of these deposits, however, gullying usually penetrates through to the underlying units.

Vegetation and land use

Vegetation on eolian deposits varies widely in the study area. Land use is also largely determined by the nature of the underlying deposits. Major exceptions are eolian sediments which blanket fluvial or glaciofluvial deposits; the fine textured eolian deposits appear to provide sufficient moisture retention to allow growth of vegetation in excess of that which the underlying gravels would support without loess covering. Good examples of such deposits may be seen capping the gravel stream terraces along Highwood River downstream of Longview. These terraces support extensive grassland.

Alluvial deposits

Alluvial deposits (A) are those deposits that were laid down exclusively by running water. Alluvial deposits in the study area are distinguished from glaciofluvial deposits on the basis of the following criteria:

1. Alluvial deposits are located along courses of existing streams which do not have an immediate glacial source.
2. The surfaces of alluvial deposits are not pitted or otherwise show signs of any previous contact with ice.
3. Internal sedimentary structures of the deposits do not indicate any deformation which might have been caused by subjacent ice meltout.
4. The deposits are not graded to any morainal features.

For the purposes of this study, alluvial deposits are subdivided into three groups based on morphology: alluvial plains, alluvial terraces, and alluvial fans.

Alluvial plains

Alluvial plains or floodplains (Ap [W) are confined to valley bottoms and are subject to periodic flooding (Smith, 1980) and attendant erosion and sedimentation (Rust, 1979; Walker and Cant, 1979). Textures of alluvial plain deposits along the larger streams of the study area such as Bow, Highwood, Sheep rivers and Willow Creek range from sand to gravel size (GP and SP soils). Stratification usually consists of thick beds of gravel (commonly greater than 1 m in thickness) with interstratification of thinner beds of gravelly sand; however, deposits predominantly consisting of sand may found locally. Smaller sluggish streams, especially those occupying glacial meltwater channels (for example, Pothole Creek), typically carry finer textured sediment loads. Consequently alluvial plain deposits adjacent to these streams are typically sand, silt, and clay, interstratified with variable amounts of gravel, and may be locally interstratified with organic deposits. Soils along these streams fall into the SW, ML, MH, CH, and locally OH in the Unified Soil Classification scheme. Map units on Map 2-1984 designating these deposits have textural modifiers such as silty to gravelly (ⓕg) or sandy to silty (sⓕ). Often, however, alluvial plains along such streams are too narrow to depict at the scale of mapping.

Thicknesses of alluvial plain deposits are highly variable and cannot be generalized. Bedrock may protrude above the stream bed in the Foothills or Front Ranges. Gravel pits along Bow River indicate thicknesses of more than 3 m.

Vegetation and land use

Vegetation on alluvial plains varies with stream activity and drainage. Areas of the channel subject to frequent flooding or inundation due to lateral migration of the stream are typically devoid of vegetation or may have sparse coverings of willows, alders, poplars, and grasses. In mountain areas, dryas and juniper may be common. Less active areas along the alluvial plain usually have thickets of willows, alders, and poplars. These thickets may grade into larger trees of the same type or mixed deciduous trees and conifers, depending on the location of the site. Areas of poor drainage or standing water along the margins of floodplains usually have coverings of water-loving vegetation such as sedges.

Land use on alluvial plains is at present confined to sand and gravel mining and to recreational activities. This sand and gravel mining of alluvial plains accounts for most of the gravel mined in the study area; most of the production currently comes from the Bow River floodplain in the southeast part of the city of Calgary.

The high permeability of alluvial plain deposits makes them unsuitable sites for any solid or liquid waste disposal or storage of any potentially toxic materials which could infiltrate into the gravels and pollute adjacent streams or groundwater.

The location of permanent structures or settlement on alluvial plains is hazardous due to the certainty of periodic floods and to the lateral migration of active stream courses across the floodplain which may undetermine structures. Structures located on alluvial plains should be restricted to temporary ones required for industrial activities such as gravel mining or to permanent ones designated to withstand periodic flooding.

Alluvial terrace deposits

Alluvial terraces (At) are remnants of past alluvial plains which existed at higher levels than the present alluvial plain (Jackson et al., 1982). They can form flights of step-like surfaces along valley walls. Alluvial terraces are best seen along Bow and Highwood rivers but are present in many sizes along almost all streams of the study area. Alluvial terraces consist of a level, gravel-capped bedrock surface or a level gravel deposit bounded on the river side by a steep descending slope and on the upland side by an ascending slope.

Texture and modifying processes

The textures of alluvial terrace deposits are similar to those of alluvial plain deposits. Deposits along the larger streams such as Highwood River consist of well sorted sandy gravels with local sandy interbeds. Smaller streams such as Tongue Creek have proportionally more fine deposits, such as silty sands, interstratified with gravels. Thickness of alluvial terrace deposits may range from veneers less than 1 m in thickness to perhaps 10 m or more in some locations. Erosional processes are of little consequence on alluvial terrace deposits due to their flat topography and high permeability; exceptions occur along their margins where undercutting by the river may cause slope failures and promote gullying on cut faces.

Vegetation and land use

Vegetation cover on alluvial terrace deposits is typically grass in the easternmost Foothills and Prairies and forest in the Foothills and Front Ranges. Grazing and sand and gravel mining are the two most common land uses. Sand and gravel deposits are typically of similar texture to adjacent alluvial plains.

Alluvial fan deposits

Alluvial fan deposits (Af [W) are located at points where tributary valleys join larger valleys. At these locations the tributary stream channels commonly undergo sudden changes in hydraulic geometry with attendant decreases in their capacities to transport sediment (Bull, 1964, p. 17; 1977, p. 227). This situation causes streams to aggrade at these points, which in turn causes them to continually seek new courses as old ones become filled by sediment, especially during periods of high sediment discharge. Over the years, this process creates fan-like landforms with their apexes pointing up the tributary canyons. In mountainous areas such as the Rocky Mountains, debris flows frequently are significant components of alluvial fan sediments (e.g., Winder, 1965; Broscoe and Thompson, 1969; Eisbacher, 1979).

Alluvial fan deposits of mappable extent are almost exclusively limited to the Front Ranges and Foothills. Distances from apex to toe on many of these fans range from 0.5 to 1 km.

Texture and modifying processes

Alluvial fan deposits may range in composition from well sorted sands and gravels (GP and SP soils) to poorly sorted silty sands and gravels (GW and SW soils). Where tributary valleys are short and steep, clasts in the deposits are coarse and angular. Fissile or argillaceous rock types may make up a considerable percentage of the clasts where these rock types are present in the bedrock upstream. Sediments in the heads of these fans are typically poorly sorted with a large component of massively bedded debris flow deposits.

Many alluvial fans in the Canadian Cordillera have been shown to be inactive (Ryder, 1971a, b; Church and Ryder, 1972; Roed and Wasylyk, 1973; Jackson, in press) and relict from immediately postglacial times when the fluvial system was in a state of readjustment from glacial to nonglacial regimes (Jackson et al., 1982). Jackson (in press) developed a methodology for evaluating the occurrence and frequency of debris flows on alluvial fans. He found that fans which have been built of debris flow deposits could be recognized on the following criteria: 1) large contents of both >2 mm and <0.002 mm particles in fan sediments; 2) upper fan slopes in excess of 4°; 3) debris flow-related topography, for example, rafted boulders on the fan surface; 4) drainage basins with areas of less than 10 km^2 and internal relief greater than 500 m.

He identified fans which are presently inactive as those with fan head to toe incised trenches and widespread deposits of tephra over the fan surface. Fans which are deeply incised are designated as Af on Map 2-1984.

Vegetation and land use

Alluvial fans are predominantly forested except for areas of active channels. The chief land uses on these deposits are logging and recreation. Active alluvial fans are potentially hazardous sites for permanent structures because of periodic flooding, channel migration, and debris flow. Inactive fans are safe for construction and commonly provide most of the suitable land for building construction in many valleys. Alluvial fan deposits may be good sources of sand and gravel where they lie at the mouths of large tributary streams which drain terrain underlain primarily by resistant rock types (e.g. the alluvial fans of Ribbon Creek in Kananaskis valley). Those lying at the mouths of short, steep tributaries which drain shaly terrain are suitable only as sources for bulk fill.

Organic deposits

Organic deposits (O) include areas of high water table and/or patchy open water which are characterized by dense growth and thick accumulations of water-loving vegetation. Organic deposits may range from peat to mixtures of silt and clay-size organic and inorganic sediments. Organic deposits are flat lying and may form a patchy cover (Ov) or a continuous blanket (Ob). They are typically found in low areas where the drainage has been deranged by postglacial alteration of the land surface. The weak, mucky character of organic deposits makes any land use, except for winter recreation, difficult. A few areas of organic deposits may be sufficiently dry during some of the summer months to grow and harvest hay.

Peat bogs are relatively rare in the study area. A chain of bogs on the north side of Sheep River valley about 10 km southwest of Turner Valley are examples of peat bogs developed in a meltwater channel system. Mott and Jackson (1982) found peat accumulations of 6 m in this area. Marshy areas of high water table conditions such as Muskeg Creek valley in the Elbow River basin, which support a variety of water-loving vegetation, account for most of the organic deposits in the study area.

CONCLUSIONS

The physical and geotechnical properties of surficial deposits in the Kananaskis Lakes map area are conditioned by the bedrock from which they were derived. The erosional and depositional processes that modify these deposits are primarily determined by local relief.

Tills and glaciolacustrine sediments blanket most of the low relief easternmost Foothills and Prairies. Tills here are less stony than those occurring in the Foothills proper and the Rocky Mountain Front Ranges. Tills and glaciolacustrine sediments in the easternmost Foothills and Prairies contain significant amounts of expansive clays whereas those from farther west in the map area do not. Consequently, the tills and glaciolacustrine sediments from the eastern part of the map area have larger plasticity indices and are more expansive than those farther west in the Foothills and Front Ranges. A significant positive correlation coefficient was found between plasticity index and Proctor optimum moisture content, and a significant negative correlation was found between Proctor optimum density and plasticity index for both glaciolacustrine sediments and till in the map area. Erosional hazard is generally low on these sediments in the easternmost Foothills and Prairies. It increases with relief in the Foothills and Front Ranges. The low permeability of these deposits makes them generally good sites for solid or liquid waste storage.

Glaciofluvial deposits are primarily confined to valleys within the map area with minor deposits occurring in areas of hummocky moraine. They have been subdivided for mapping purposes on the basis of surficial form (planar or terraced versus ridged or hummocky forms). The texture and sorting of these deposits are variable. Some kame deposits may have a significant content of argillaceous clasts. The high permeability of these sediments makes them unsuitable as sites for solid or liquid waste storage.

The texture and continuity of colluvial deposits vary with elevation and relief. Bouldery, angular debris cones and aprons along mountain slopes or frost shattered angular rubble or patterned ground characterizes the colluvial mantle in areas of high elevation and relief in the Rocky Mountains. Snow and rock avalanches and periglacial processes are the dominant modifying processes. Finer colluvial veneers and blankets predominate in the Foothills. These sediments are usually sandy. Where sufficient fines are present to measure Atterberg limits, plasticity indexes are low, reflecting the nonexpansive or slightly expansive clays in the shales of the Foothills. Creep is probably the chief modifying process affecting these deposits. Erosion potential is low on very coarse colluvial sediments and moderate to high on the finer ones, depending primarily on slope.

Alluvial plain deposits are subdivided into terrace deposits, which are not prone to flooding, and presently active floodplains. These deposits represent the best source of sand and gravel in the study area.

Many of the alluvial fans in the Foothills and Front Ranges of the study area are inactive and relict from the period of higher rates of sediment yield from drainage basins immediately following deglaciation. These fans are commonly the products of both fluvial and debris flow sedimentation. The degree of fan incision and the widespread occurrence of Holocene tephras on the fan surfaces are key to identifying whether the fan is active or inactive.

Organic deposits occur in poorly drained areas. Marshes are more common than bogs in the Kananaskis Lakes map area.

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APPENDIX 1

Clay mineral preparation methods

Suspensions of the ≤0.002 mm fraction of samples were concentrated by four centrifuge runs in a 5 g/L sodium metaphosphate solution. Three slides of each sample were prepared by applying the clay-dispersant solution on glass slides and allowing it to dry at room temperature. One slide was then glycolated as a test for the presence of expansive clays; a second was heated to 550°C to destroy kaolinite; and a third was left untreated. Samples were analyzed on a Norelco 4227/1 X-ray diffractometer at a scanning speed of 2° 2θ/minute between 3° and 33° 2θ at 45 kv and 21 mA using Cu radiation. The estimates of relative abundances of minerals present were made from peak heights of glycolated slides for montmorillonite, chlorite, mica, and kaolinite at 17Å, 7Å, 10Å, and 7Å respectively (1Å = 0.1 nm). The abundances of the nonclay minerals quartz, feldspar, calcite, and dolomite were estimated according to peak heights at 4.25Å, 3.20Å, 3.03Å, and 2.89Å. The presence of both chlorite and kaolinite in many of the samples necessitated further work in order to determine the relative percentages of kaolinite and chlorite accounting for 7Å peak. The procedure of Biscaye (1964) of slowly scanning the 3.58Å (002) kaolinite peak and 3.45Å (004) chlorite peak and using their intensities as measures of relative kaolinite and chlorite abundances was used. All samples studied in this manner were run on the Norelco diffractometer at 1/8° 2θ/minute.

The abundances of the clay sized minerals were corrected for Lorentz polarization using the coefficients of 2:8:8:8 for 17Å montmorillonite, 7Å chlorite, 10Å illite, and 7Å kaolinite. Abundances of quartz, feldspar, calcite, and dolomite were corrected using the empirical coefficients of 10:10:4:3 (Bayliss et al., 1970).

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